



Roughness and distribution of slopes on Vesta and Ceres

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Motivation: why study roughness?

- Why not? We have the data.
- Roughness map provides a synoptic view of the surface texture that can aid geologic mapping.



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Outline

- **Slopes**
- **Roughness**
- **Roughness maps of Vesta and Ceres**
- **Composite roughness maps of Vesta and Ceres**
- **Summary**

Data

Vesta

- SPC shape model from LAMO (Gaskell, 2012) with 71-m resolution
- SPG shape model from HAMO (Jaumann et al., 2012) shape model with 94-m resolution

Ceres

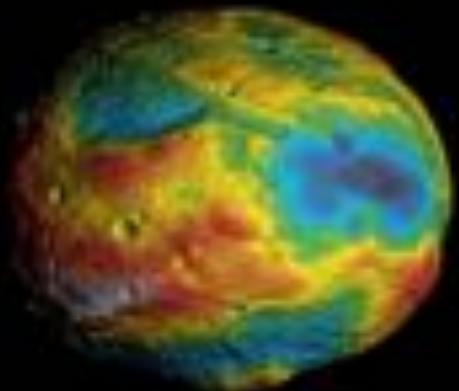
- SPC shape model from LAMO (Park et al., 2018) with 82-m resolution
- SPG shape model from HAMO (Preusker et al., 2016) with 135-m resolution

- For this study, we focused on SPC model because of its higher resolution.

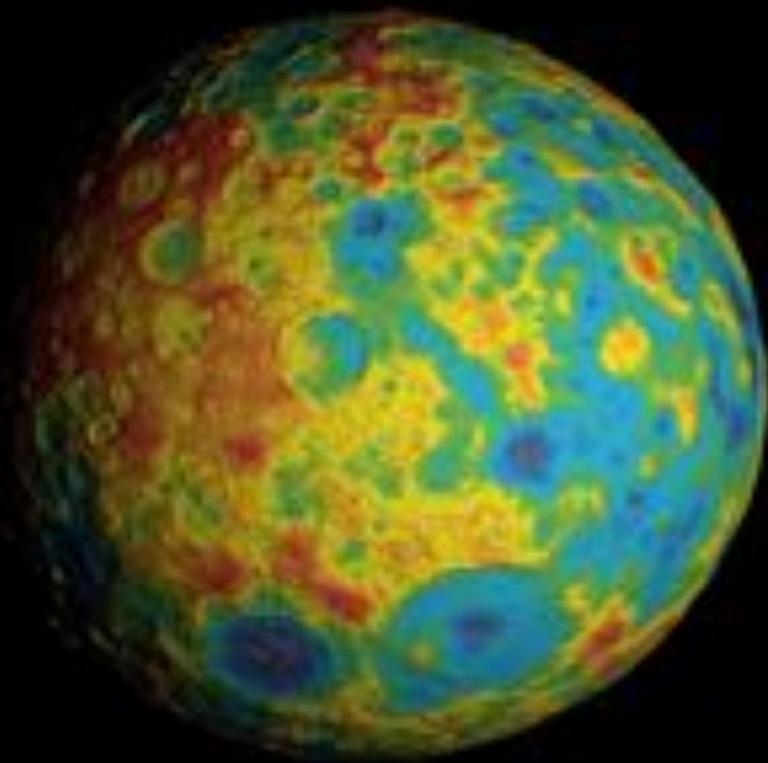
*HAMO – high altitude mapping orbit

*LAMO – low altitude mapping orbit

Vesta and Ceres shapes

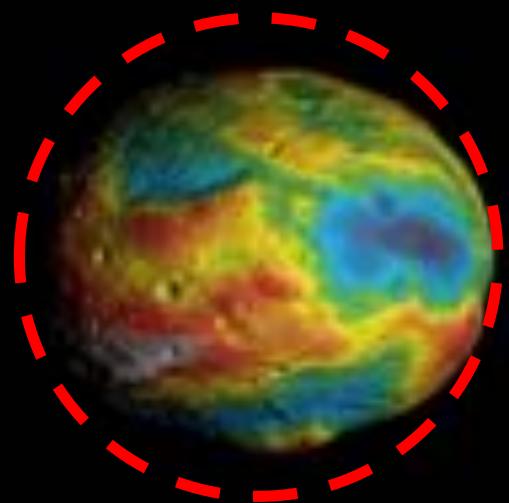


Gaskell, 2012

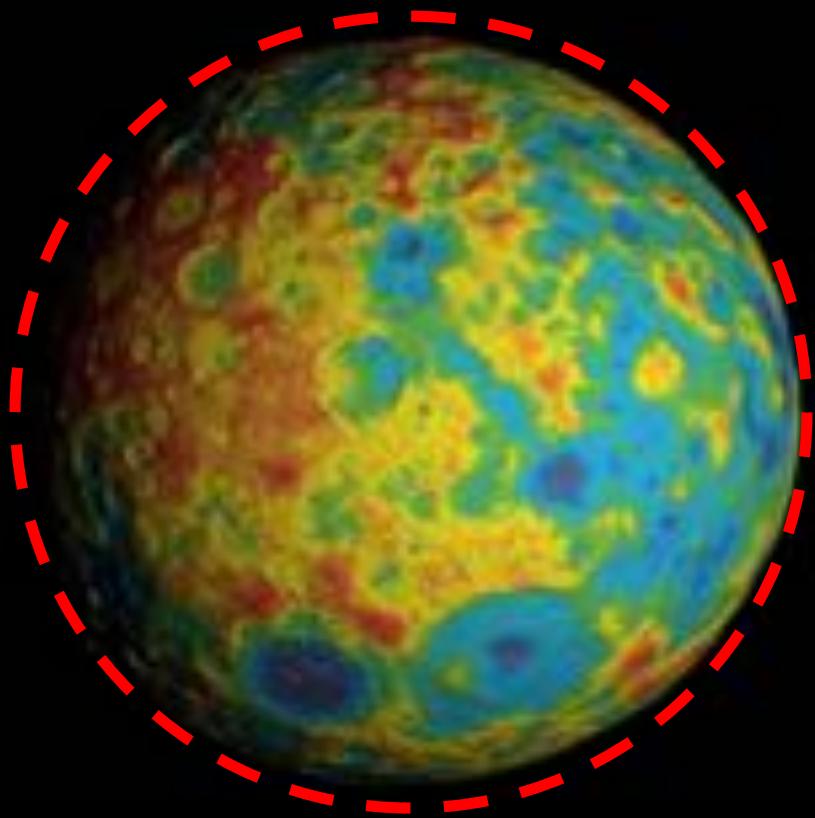


Park et al., 2016

Vesta and Ceres shapes



Gaskell, 2012

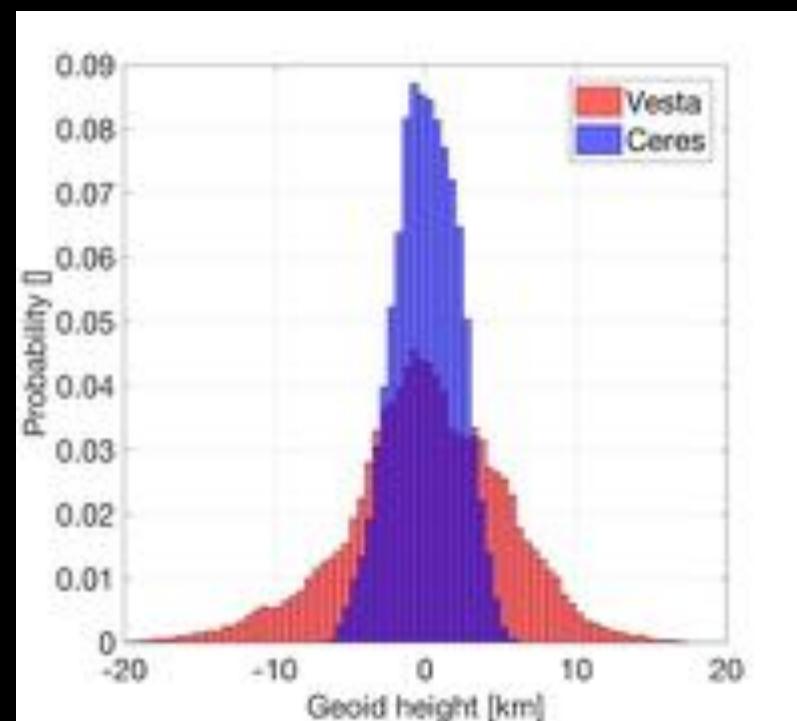


Park et al., 2016

Vesta and Ceres topography

Hypsograms of Vesta and Ceres

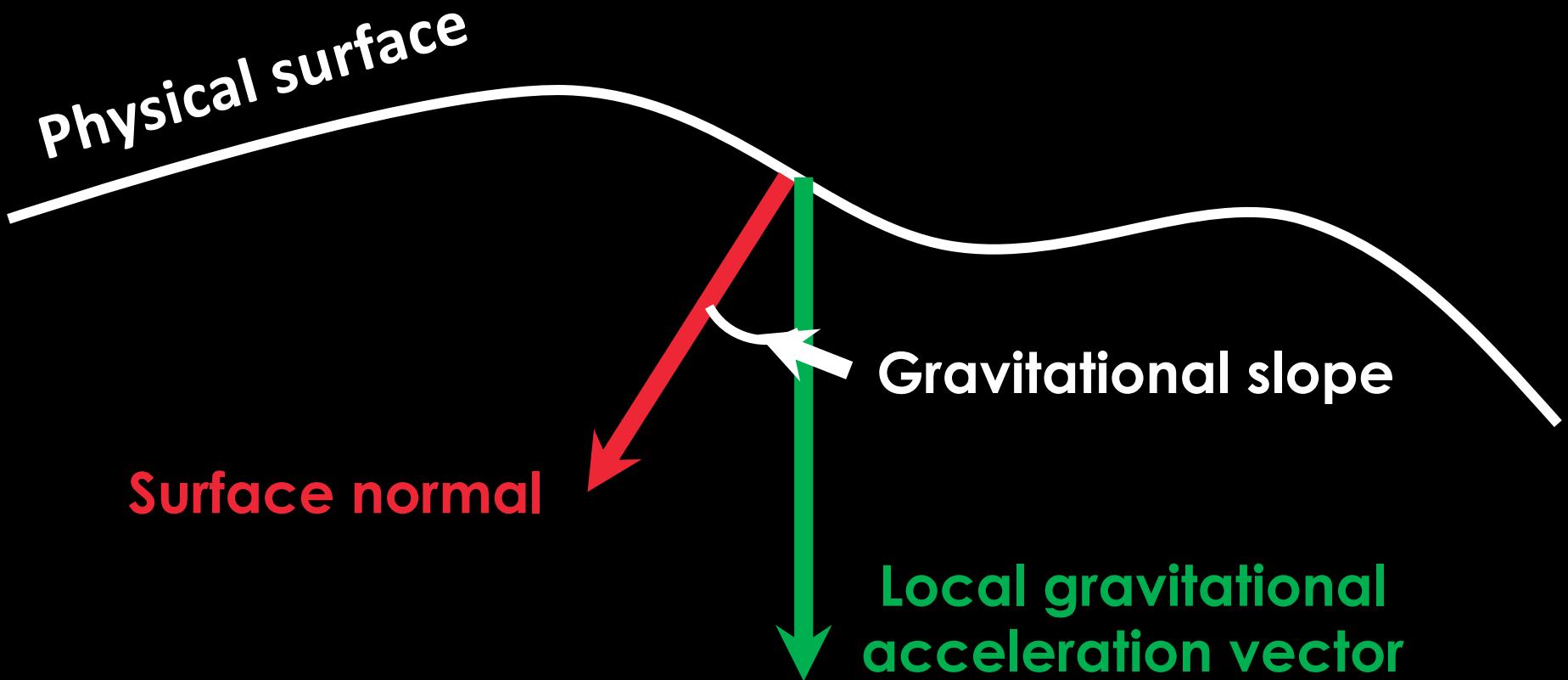
Parameter	Vesta	Ceres
Radius range (km)	80.1	44.5
Polar flattening	0.2038	0.0770
Equatorial flattening	0.0262	0.0043
equatorial/polar	12.9%	5.6%
Geoidal height range (km)	37.9	13.2
Geoidal height RMS (km)	5.2	2.1



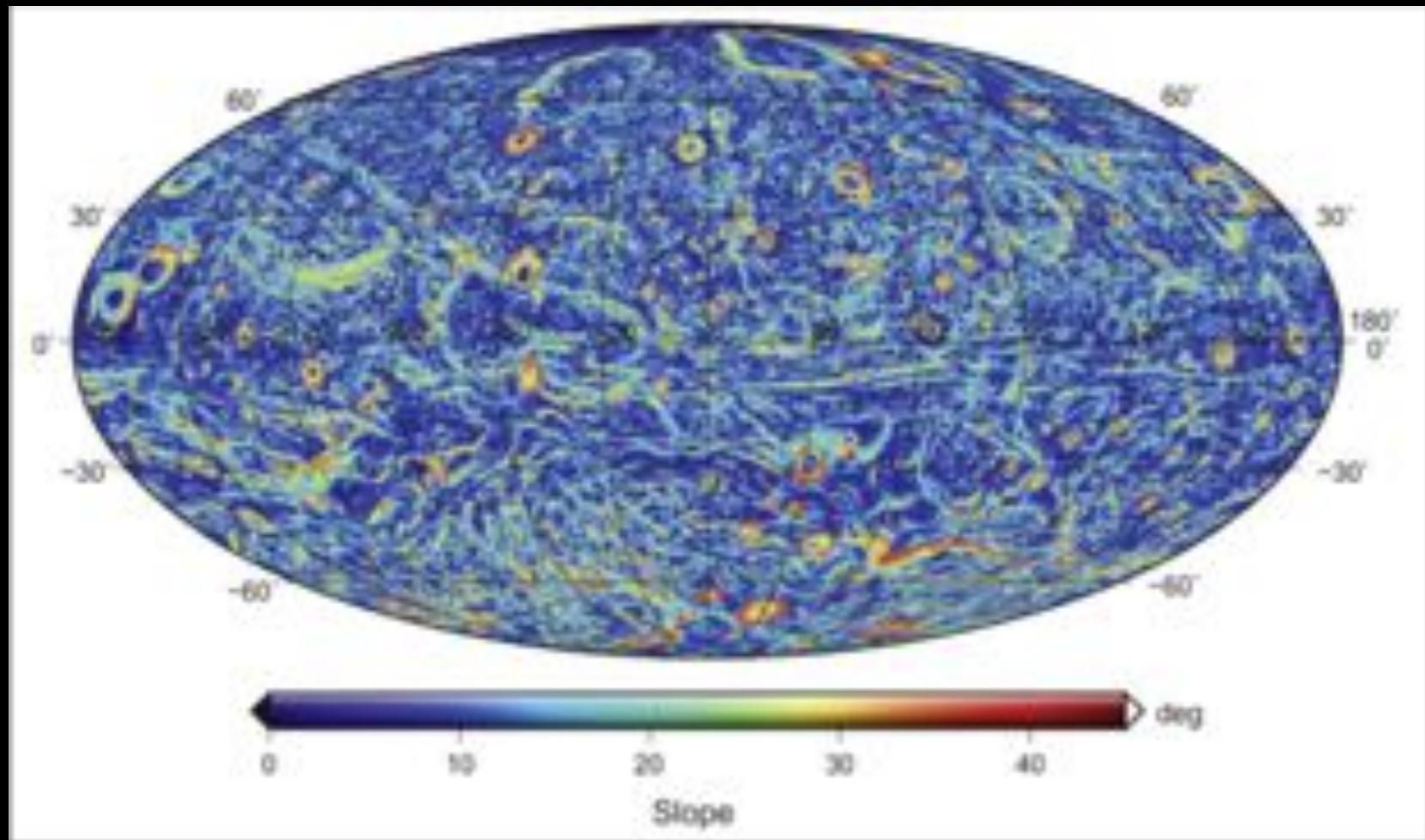
- Ceres is closer to hydrostatic equilibrium than Vesta
- Smoother topography at Ceres

*Hypsogram is a fancy word for the “histogram of elevations”

Gravitational slope

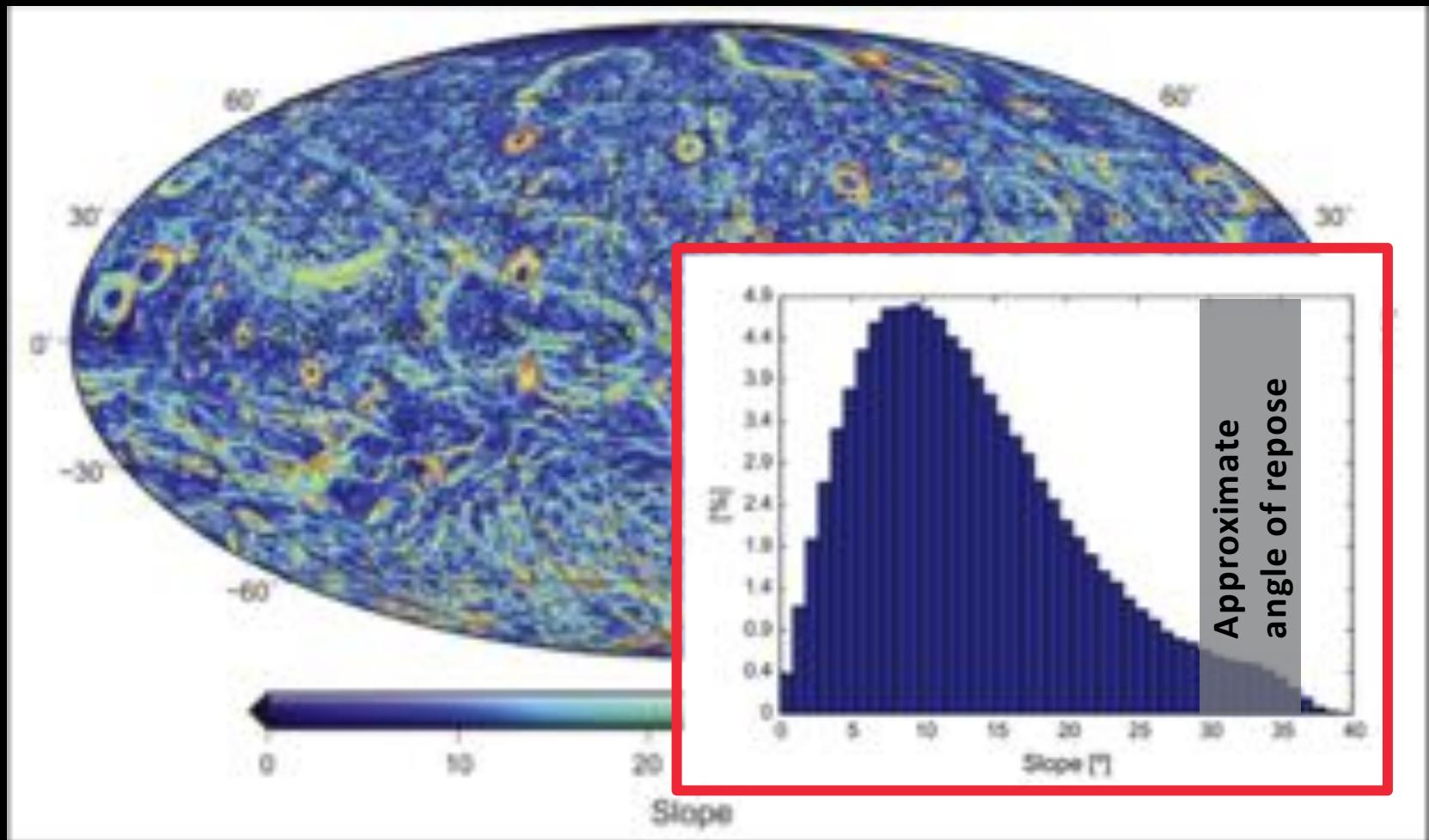


Gravitational slopes of Vesta



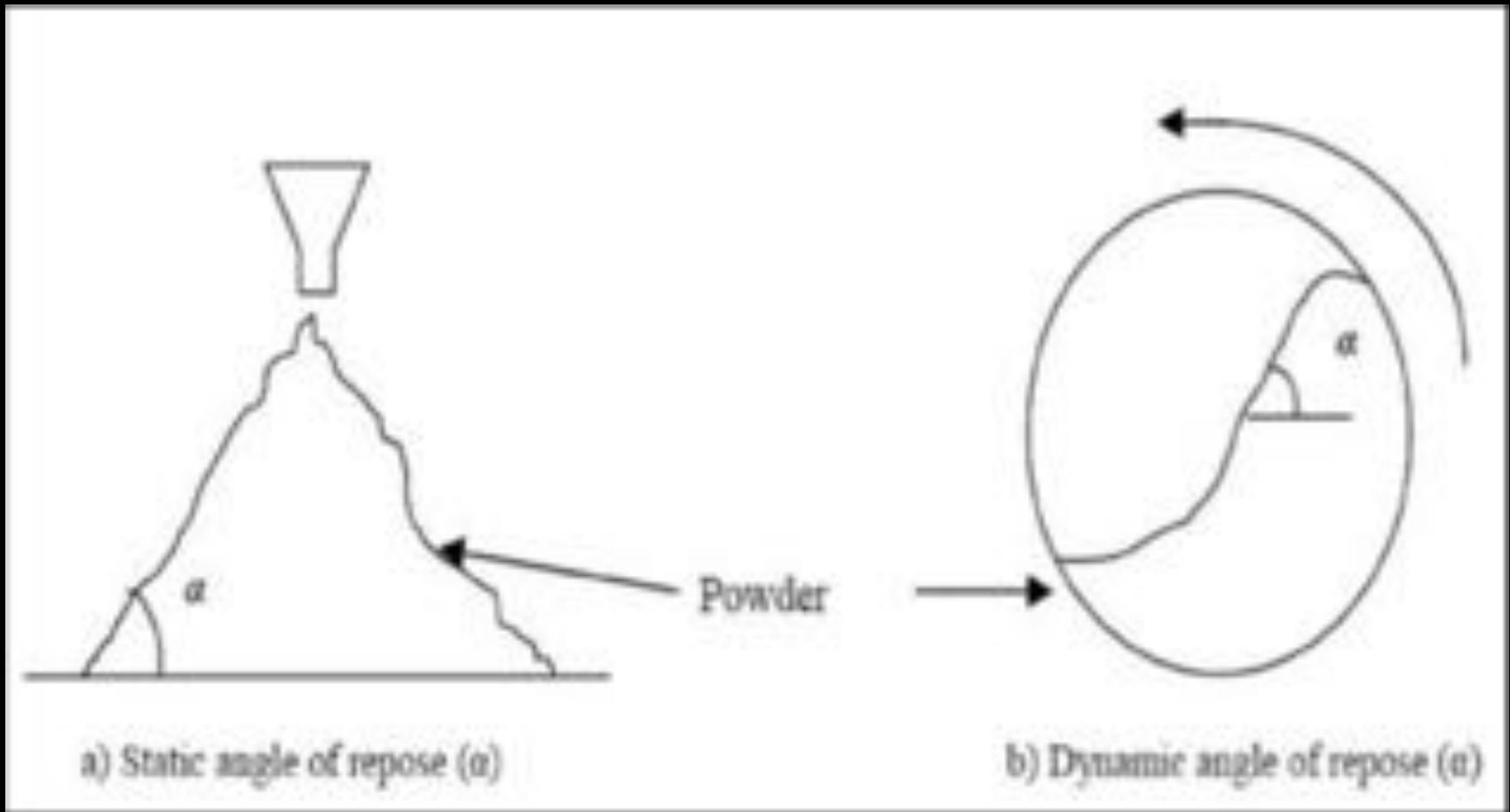
Ermakov et al., 2014

Gravitational slopes of Vesta



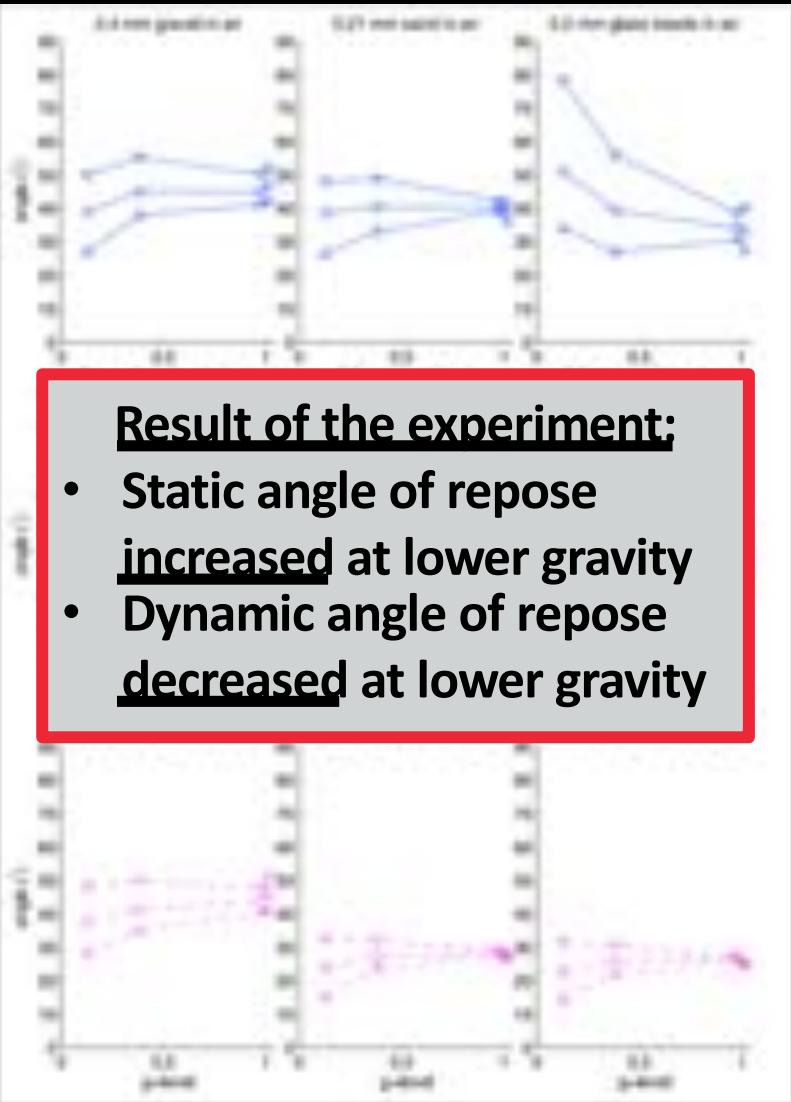
Ermakov et al., 2014

Angles of repose



Beakawi Al Hashemi et al., 2018

Angle of repose and surface gravity



- Result of the experiment:**
- Static angle of repose **increased** at lower gravity
 - Dynamic angle of repose **decreased** at lower gravity



Figure 5. The experimental setup. Cylinders are 0.21 m in diameter. Cameras are located to the left.

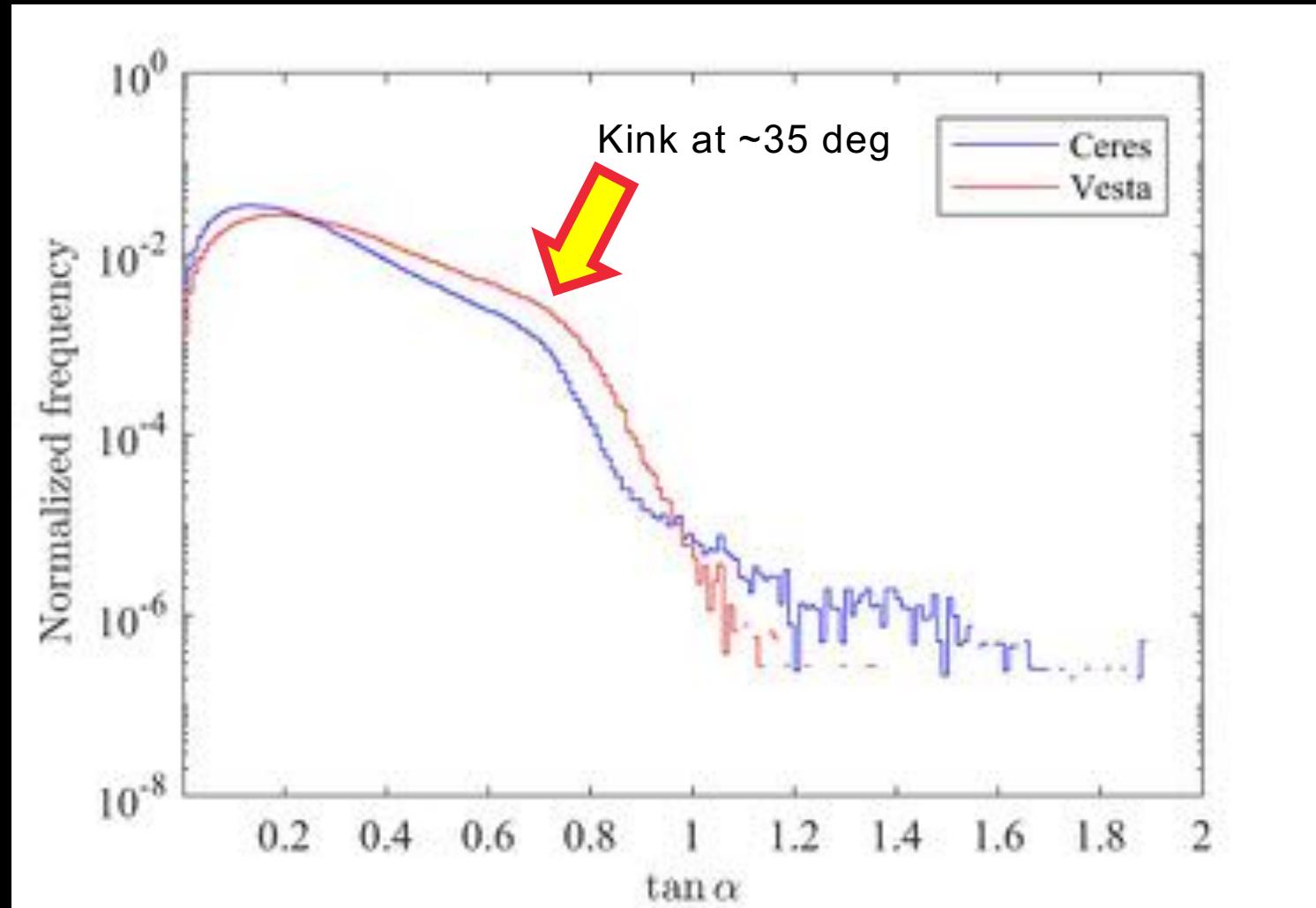


Figure 2. The Cessna Citation aircraft of Delft University of Technology and the Dutch National Aerospace Laboratory used for the parabolic flights.

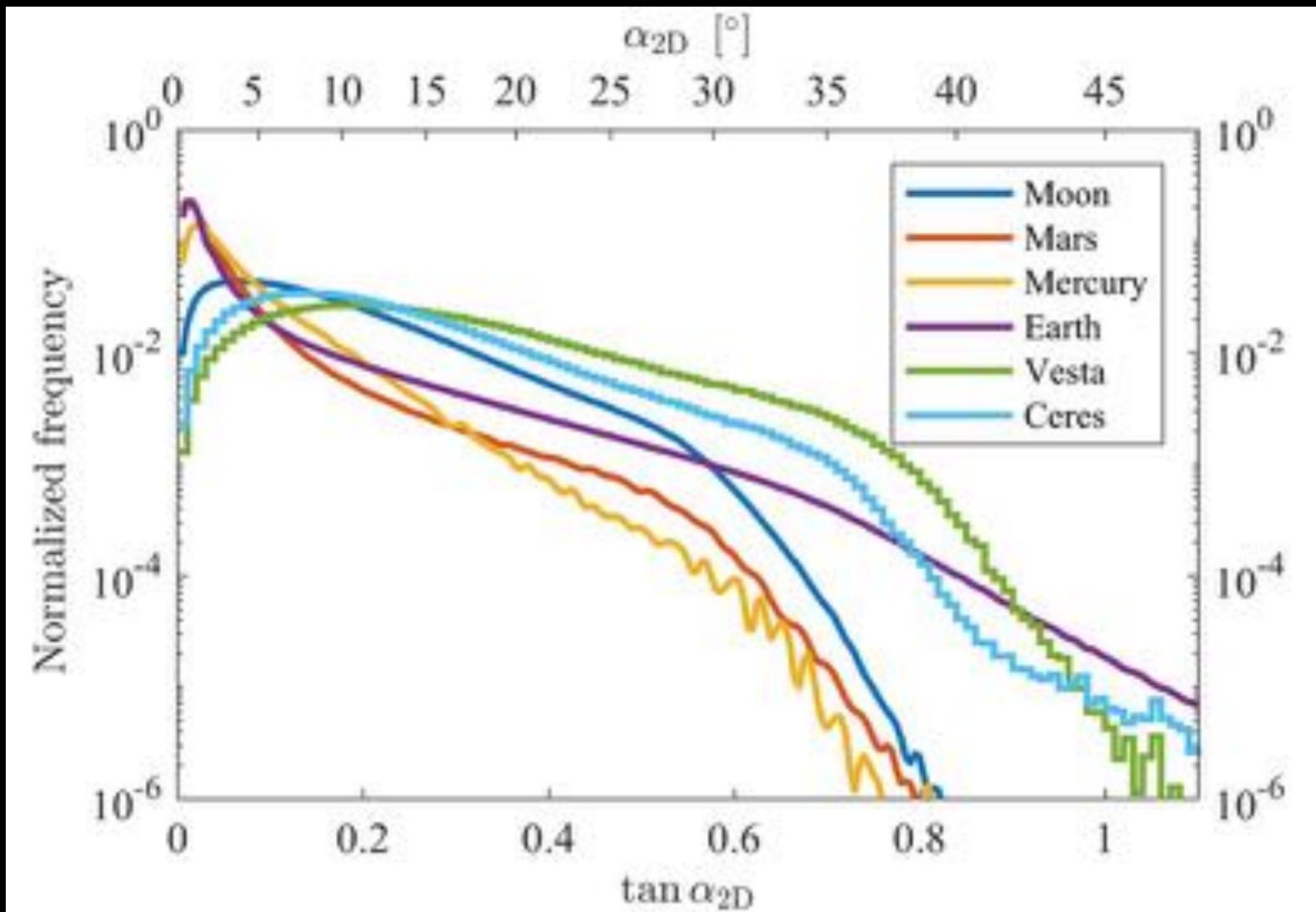
Figure 9. Time-averaged angle, static angle of repose and dynamic angle of repose for each sediment. Same as Figure 8 without data. Maximum is calculated as 90% percentile from static angles (see Figure 6) and minimum is calculated as 10% percentile from dynamic angles.

from Kleinhans et al., 2011

Distributions of slopes



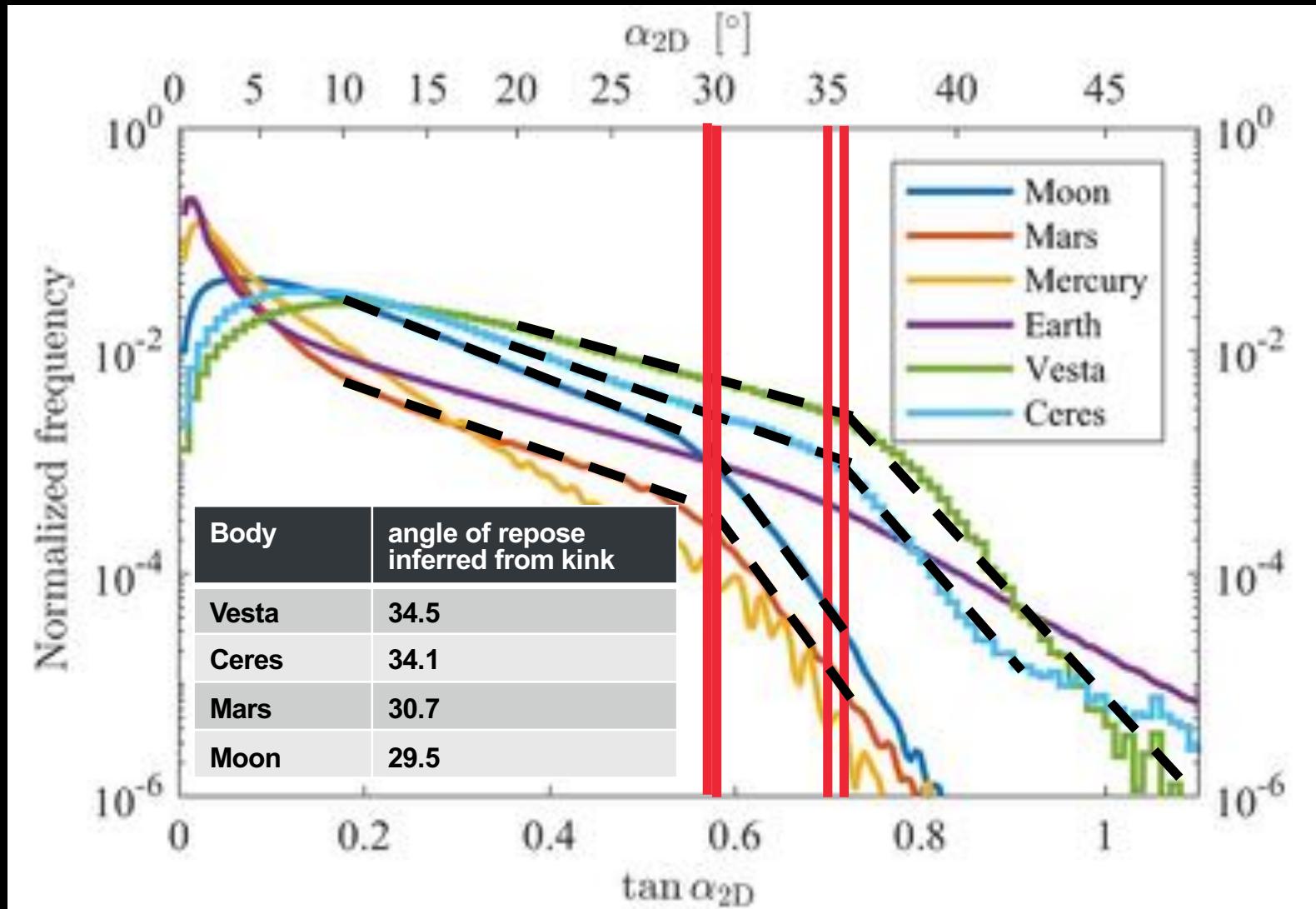
Distributions of slopes



Ermakov et al., in prep

COSPAR, 14-22 July, 2018, Pasadena, CA, USA.

Distributions of slopes



Ermakov et al., in prep

COSPAR, 14-22 July, 2018, Pasadena, CA, USA.

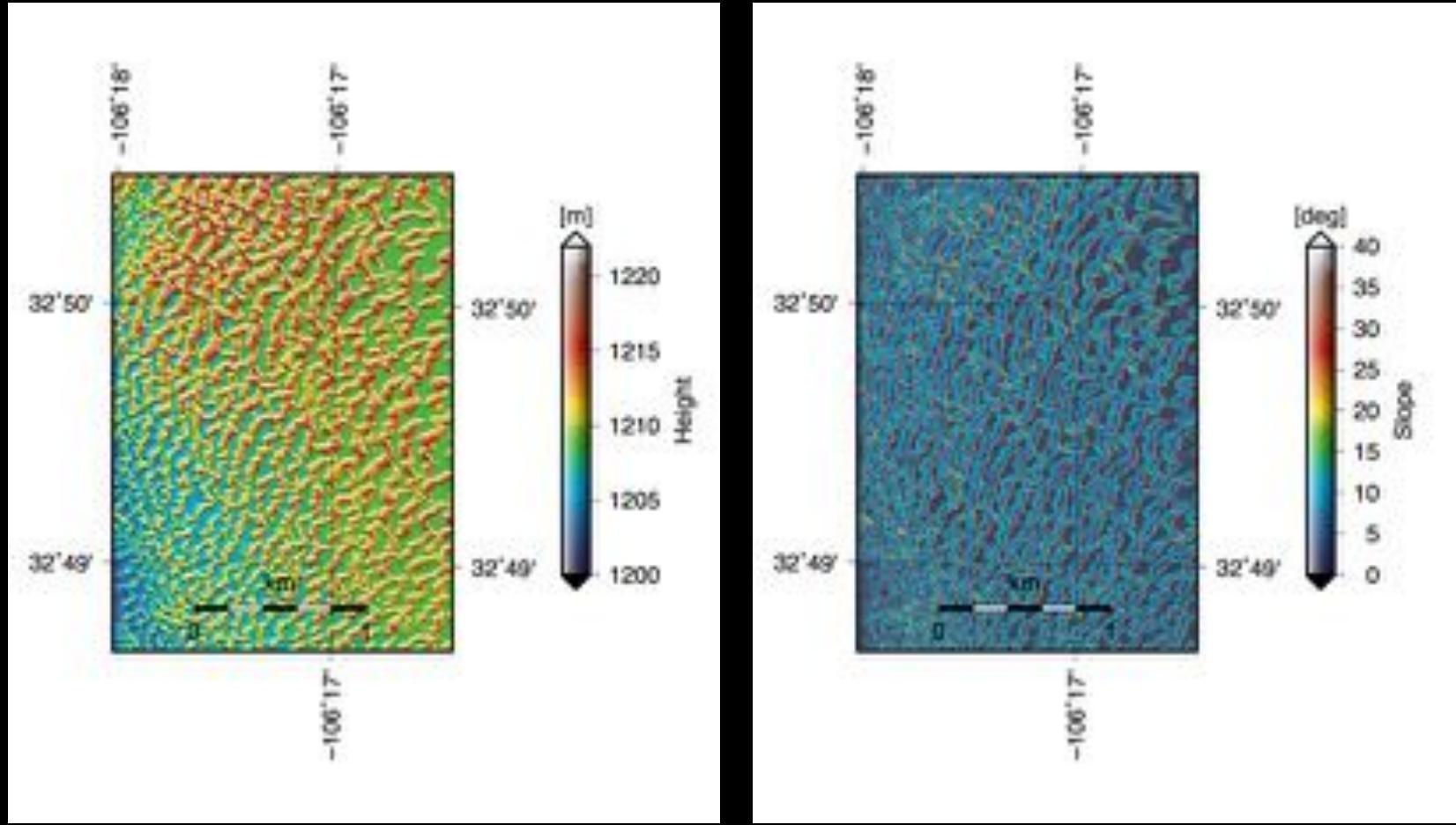
Terrestrial dunes

White Sand National Monument, New Mexico

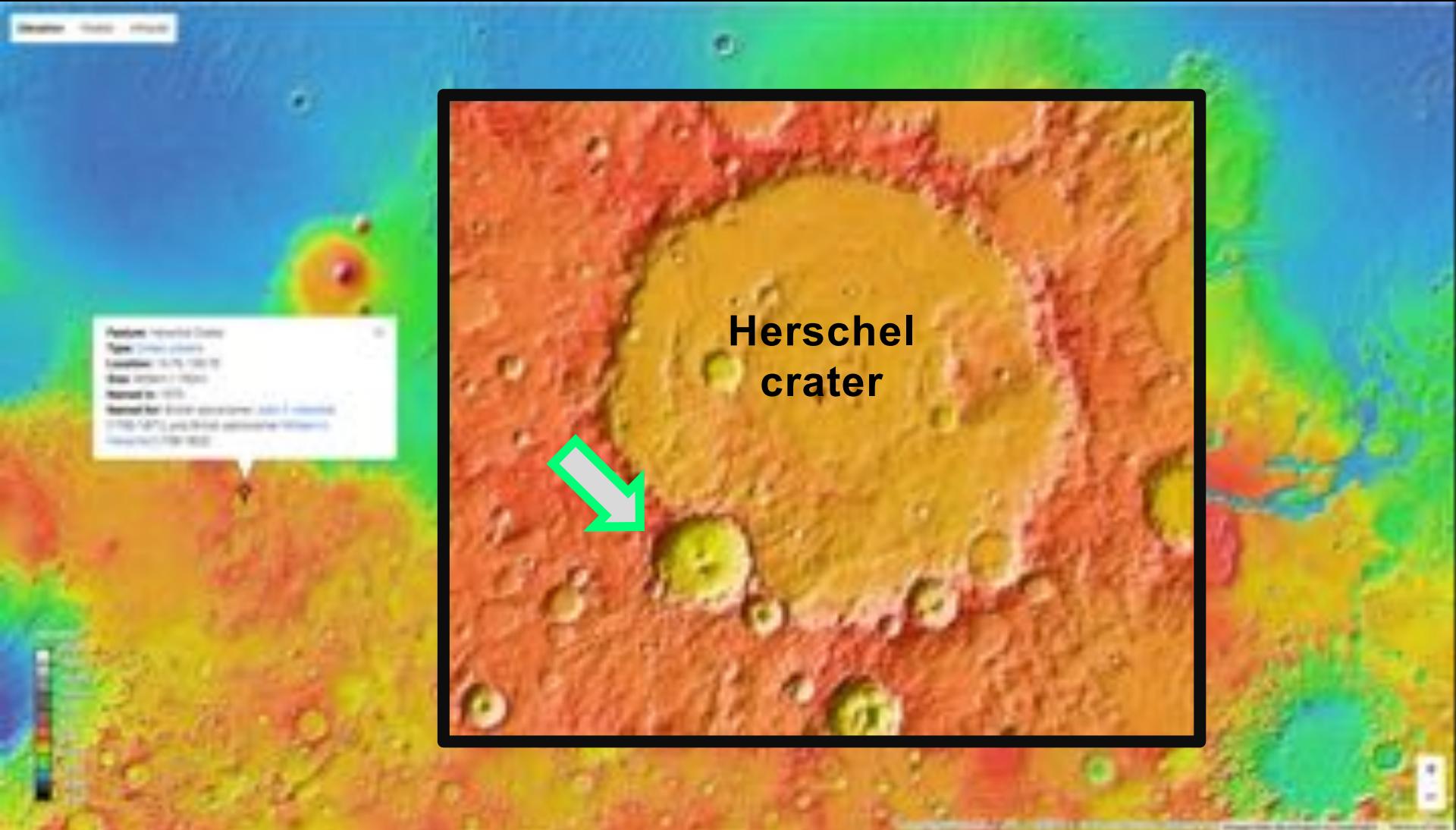


Terrestrial dunes

White Sand National Monument, New Mexico

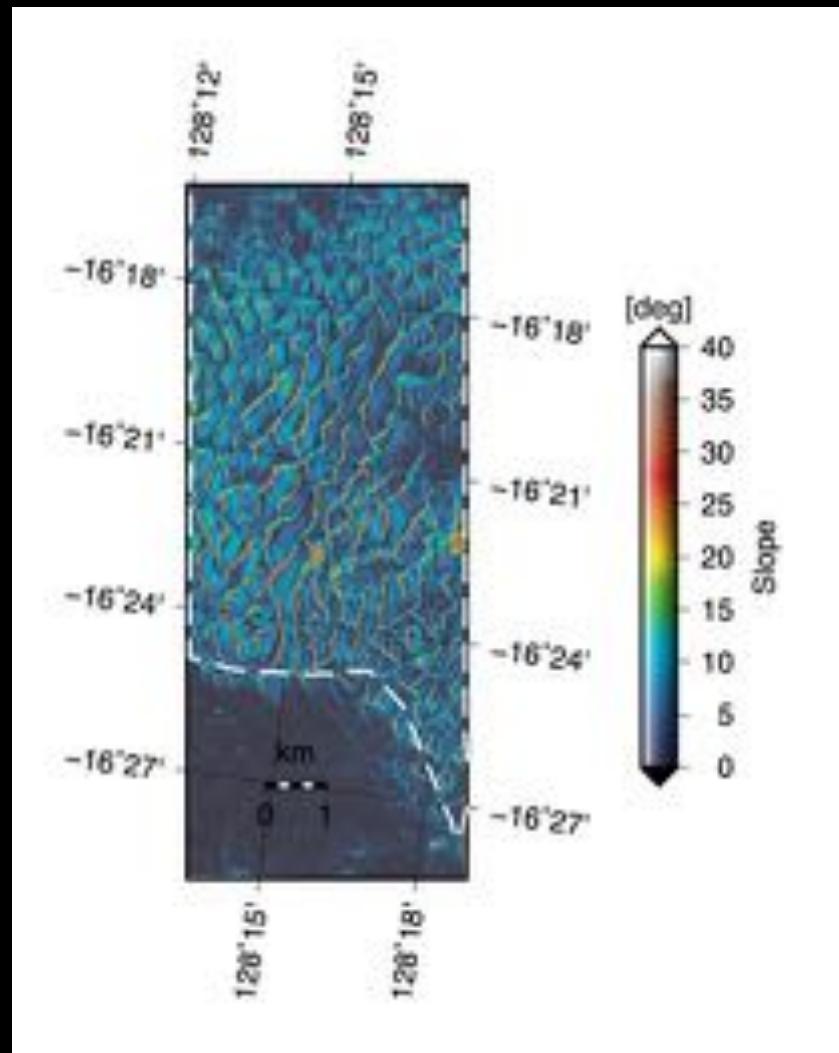
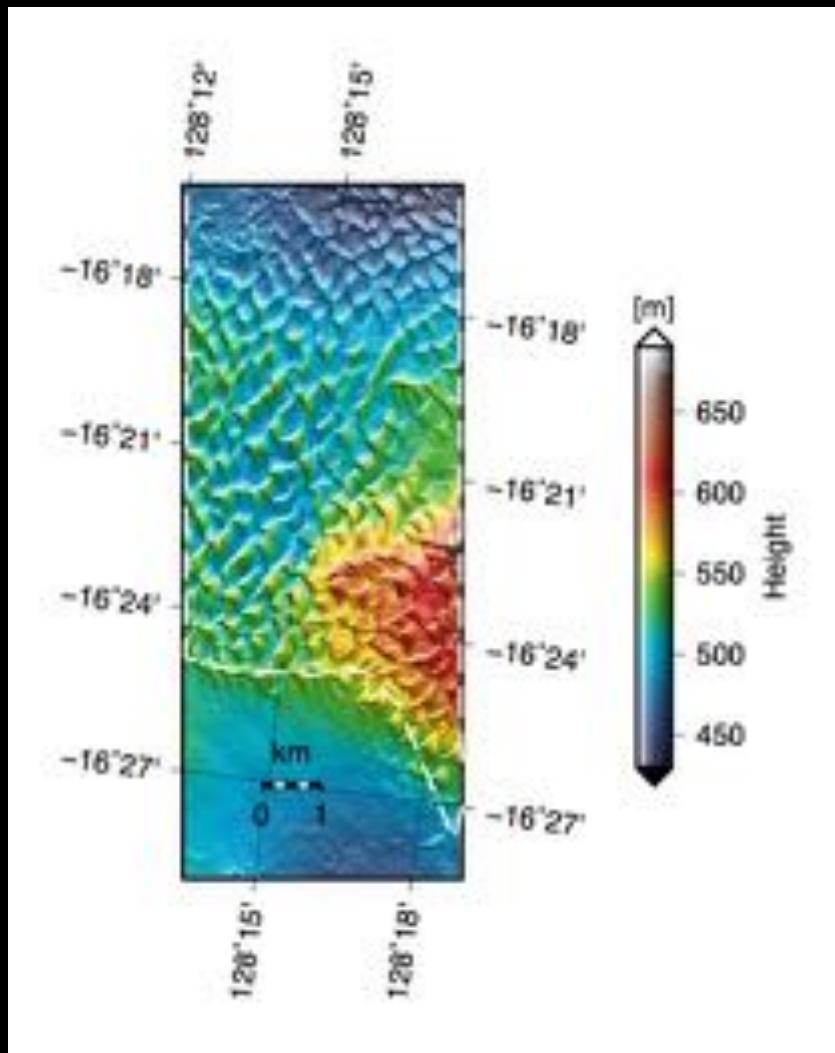


Martian dunes

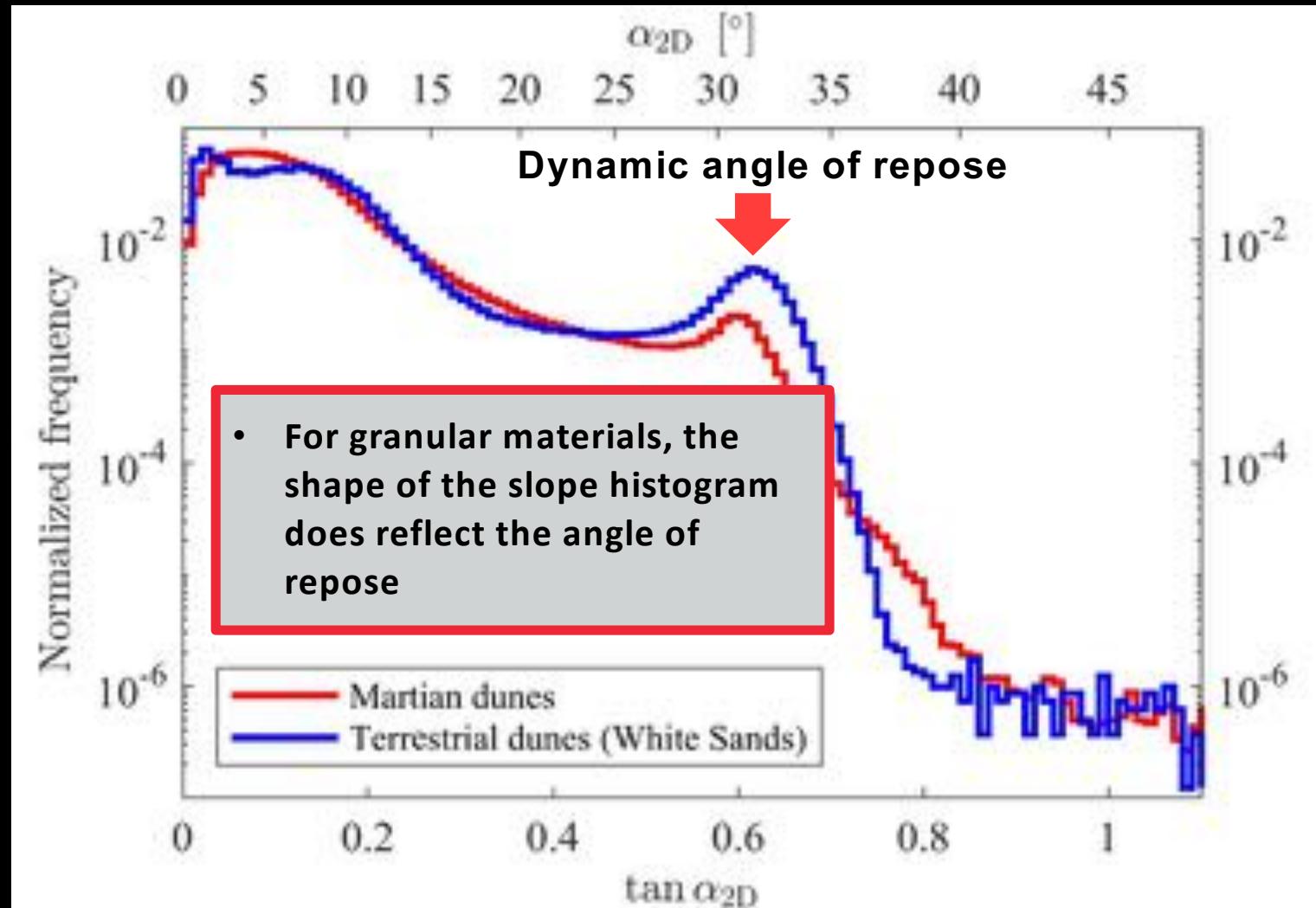


Martian dunes

Crater Southwest of Herschel Crater



Distribution of slopes on dunes

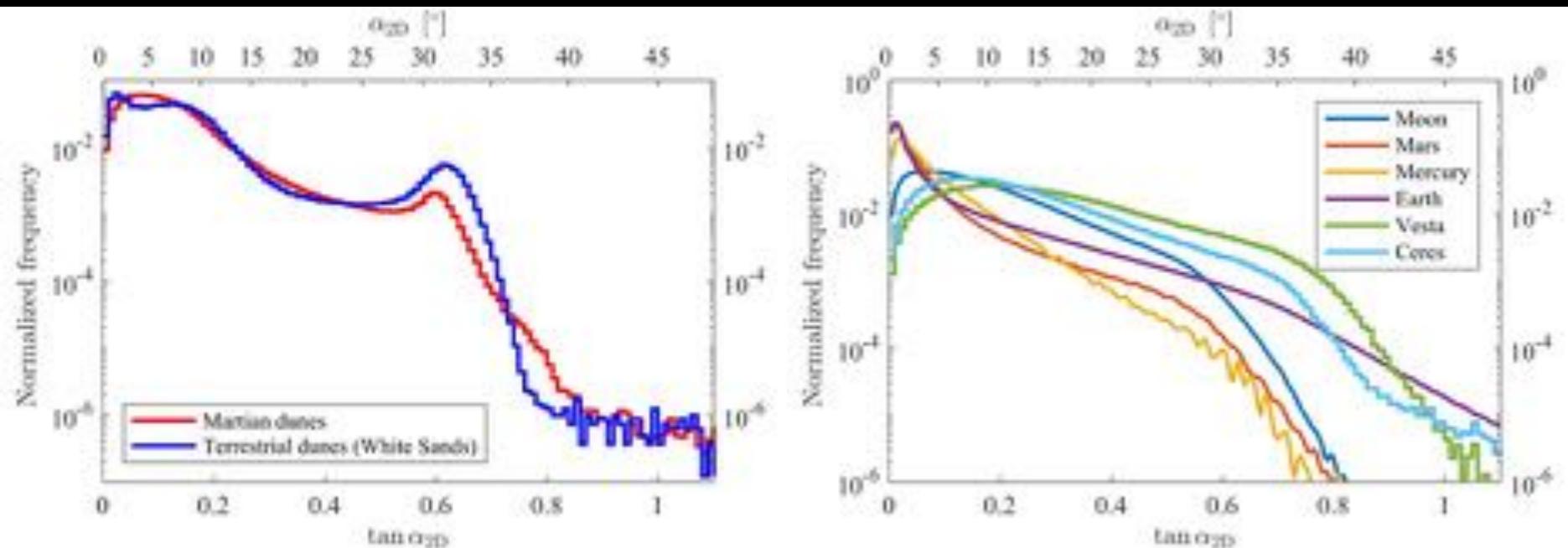


Ermakov et al., in prep

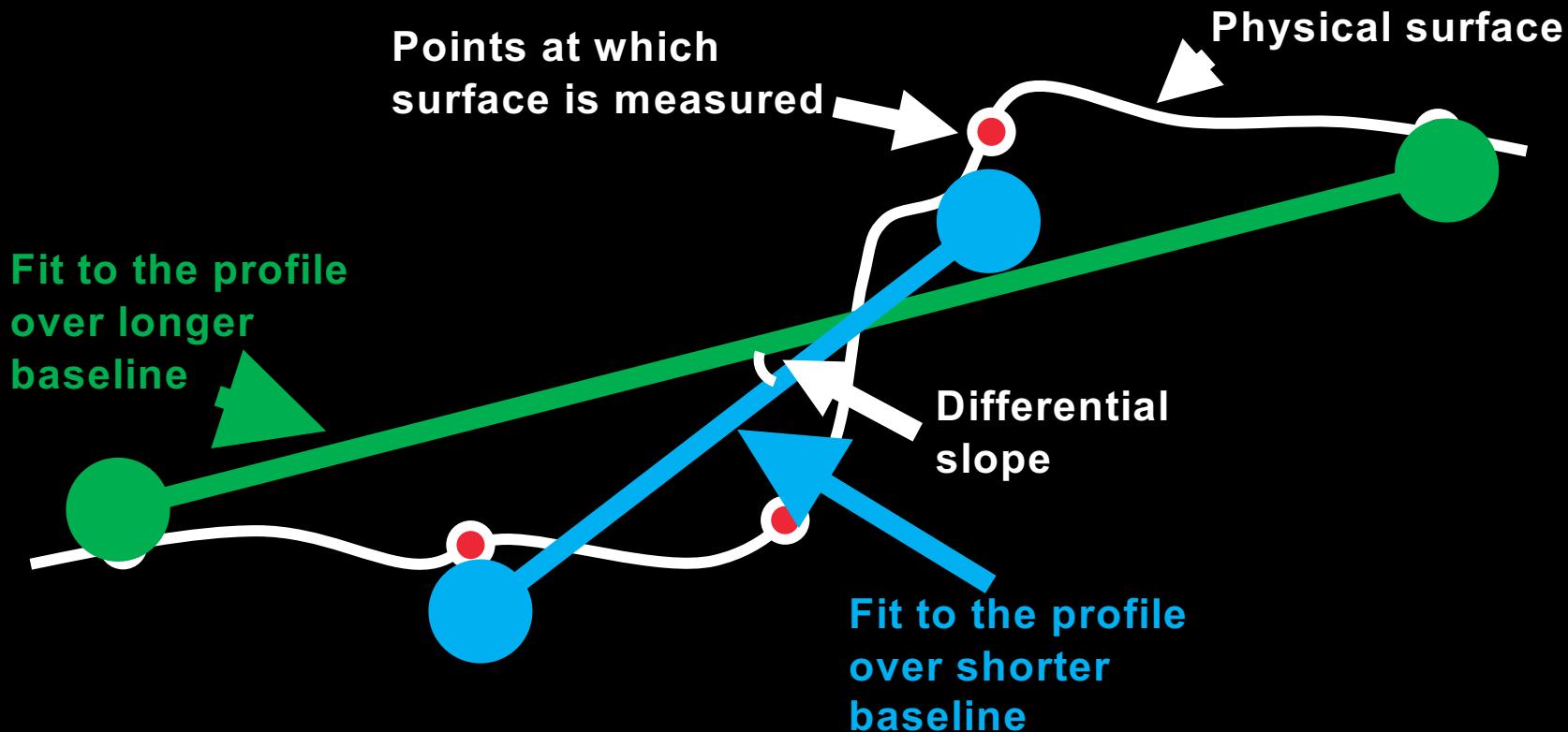
COSPAR, 14-22 July, 2018, Pasadena, CA, USA.

Distributions of slopes

- Vesta and Ceres have a higher angle of repose (ϕ) than Mars and the Moon
 - $\phi_{\text{Vesta}} = 35^\circ$; $\phi_{\text{Ceres}} = 34^\circ$; $\phi_{\text{Mars}} = 31^\circ$; $\phi_{\text{Moon}} = 30^\circ$
 - If interpreted as the dynamic angle of repose, contradicts experiments by Kleinhans et al., 2011
 - Surface gravity? Composition? Particle shape?



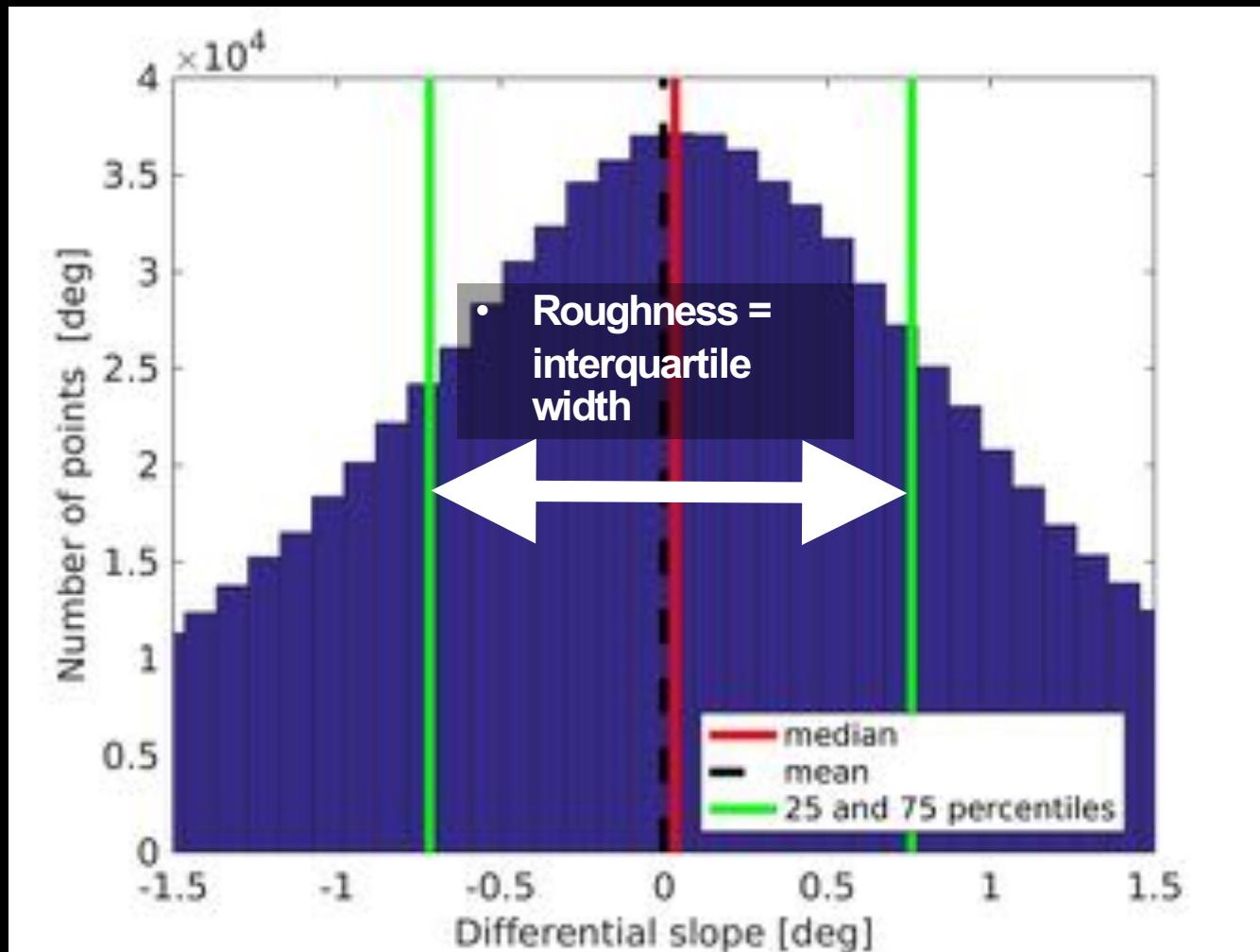
Differential slope



- By computing differential slopes, we subtract longer wavelength topography variations
- In other words, differential slope within a flat but highly inclined cliff is zero

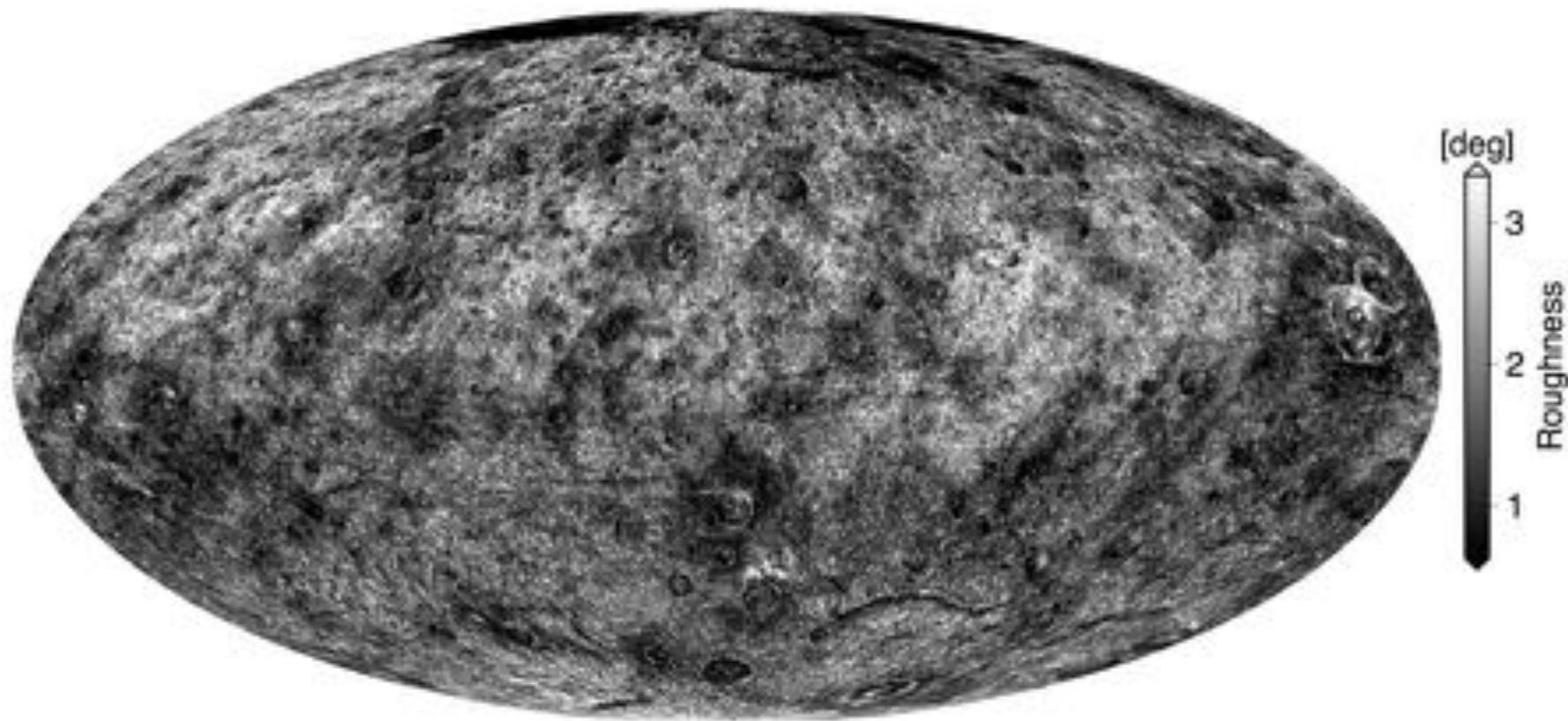
Roughness definition

Histogram of differential slopes



Vesta SPC roughness composite

B=1065m/497m



Ermakov et al., in prep

Vesta SPC roughness composite

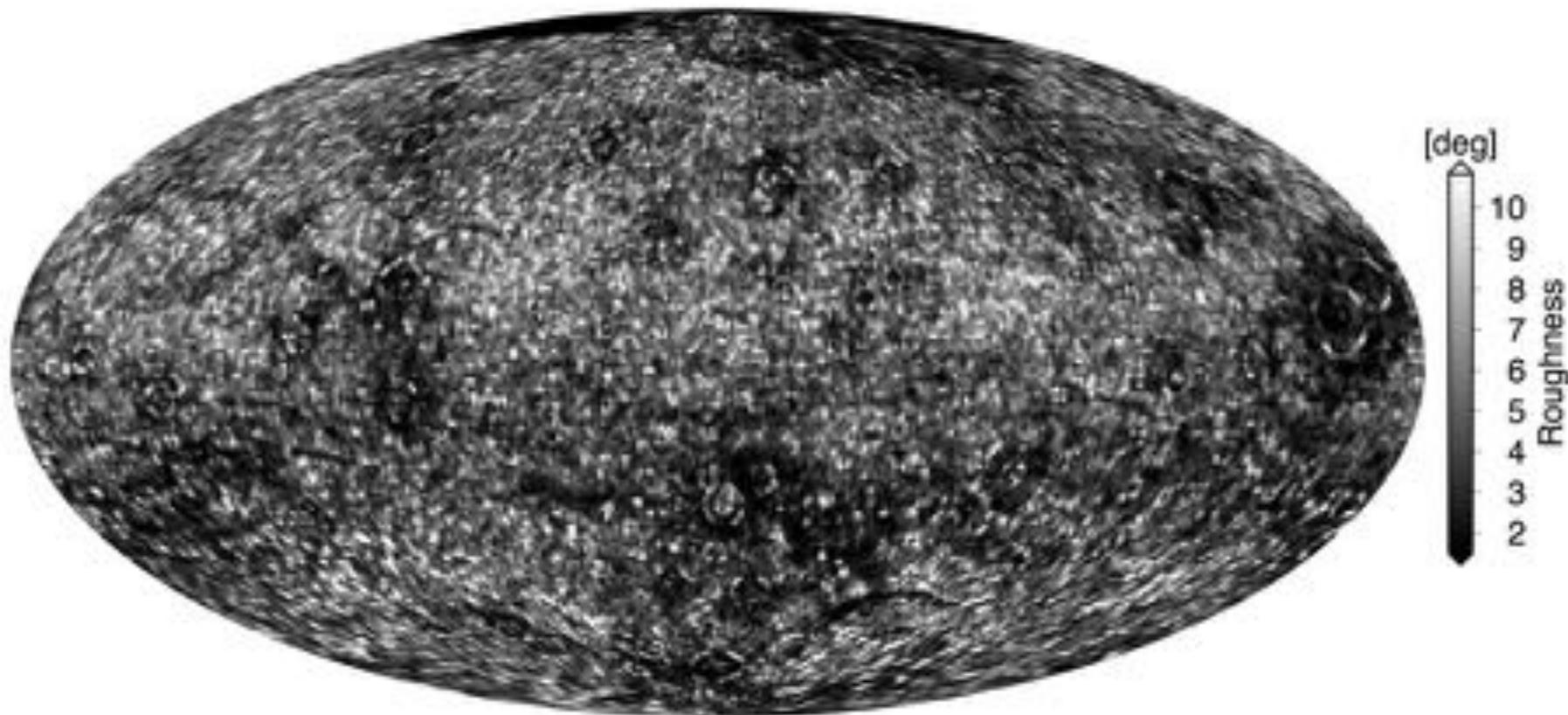
G=2769m/1349m



Ermakov et al., in prep

Vesta SPC roughness composite

R=7313/3621 m



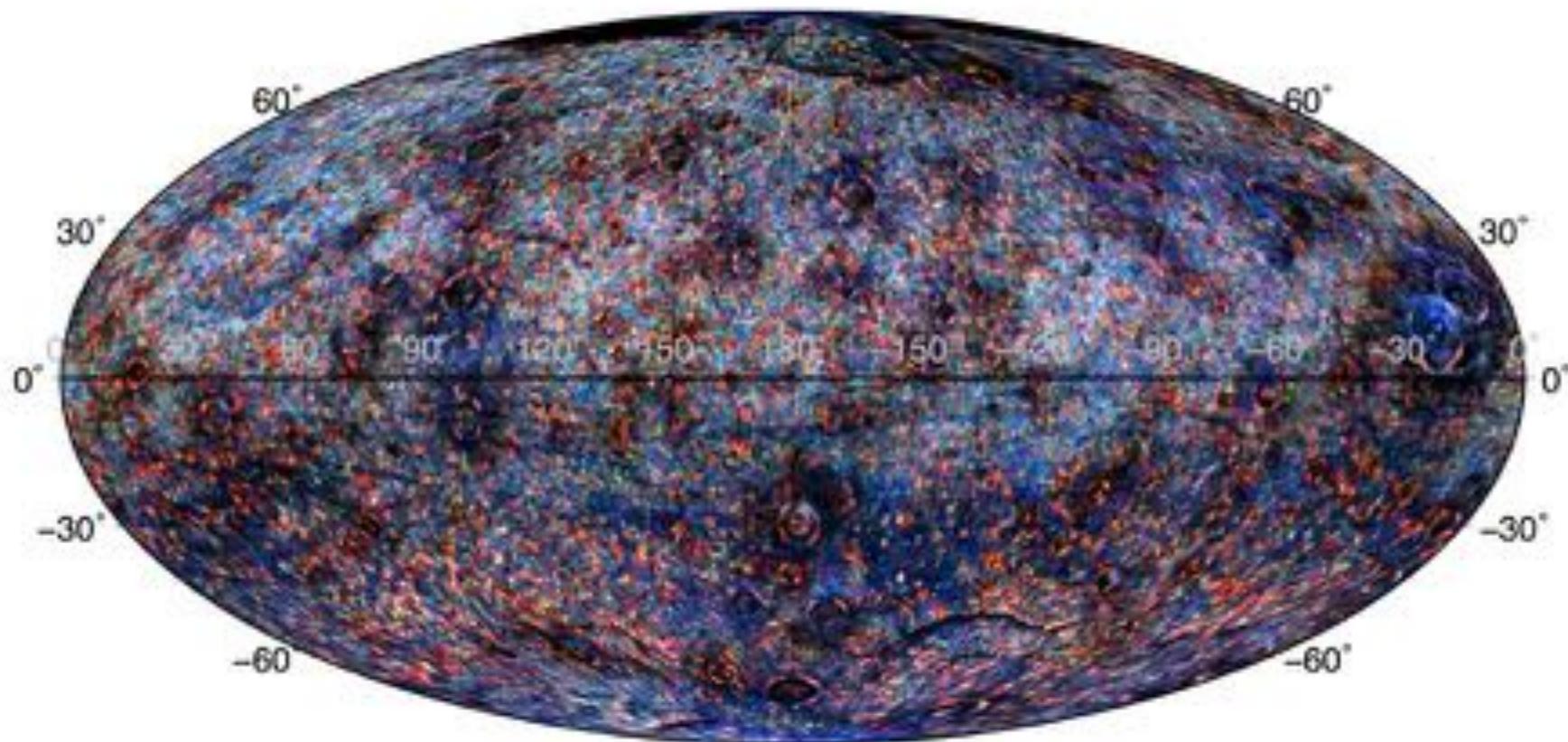
Ermakov et al., in prep

Vesta SPC roughness composite

B=1065m/497m

G=2769m/1349m

R=7313/3621 m



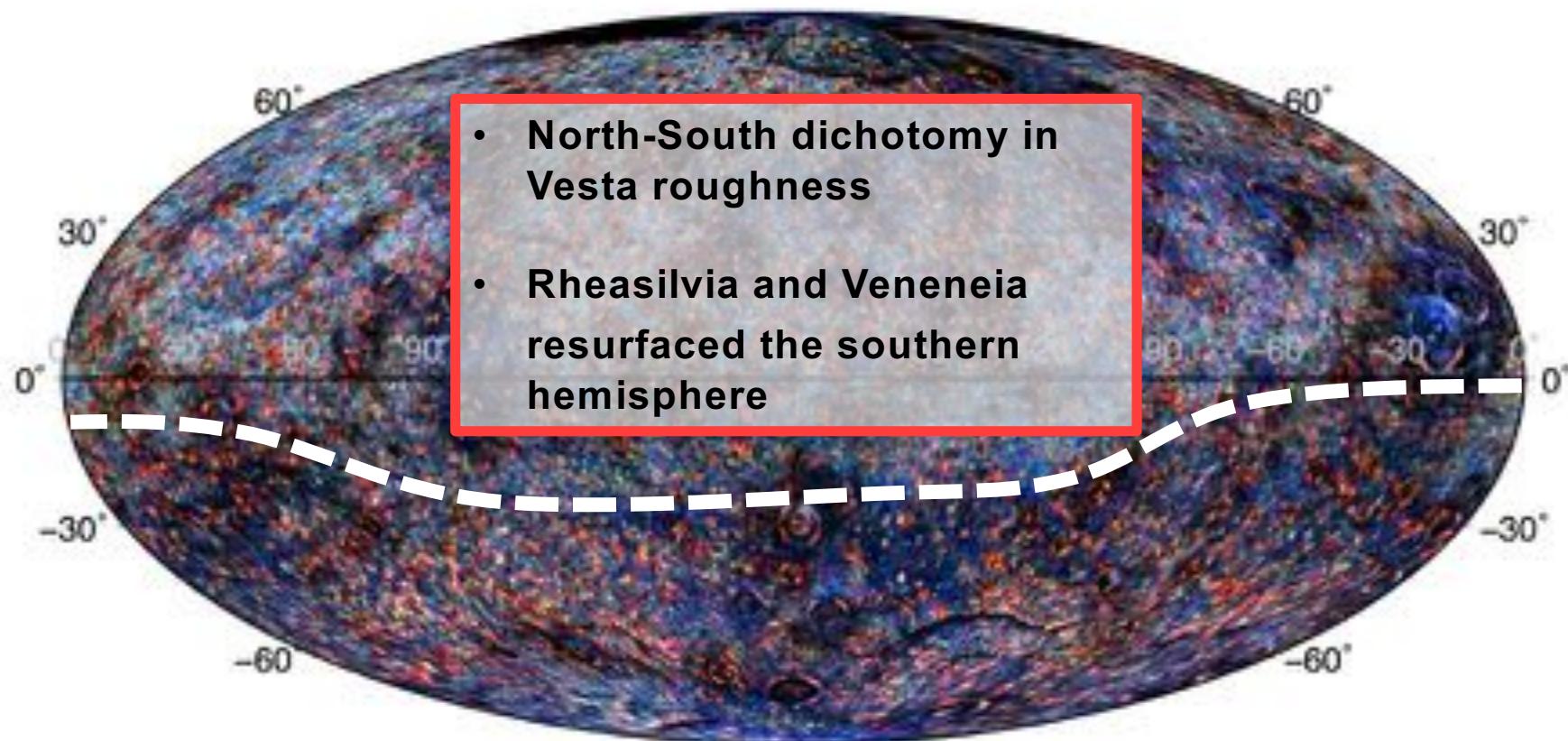
Ermakov et al., in prep

North-South dichotomy

B=1065m/497m

G=2769m/1349m

R=7313/3621 m



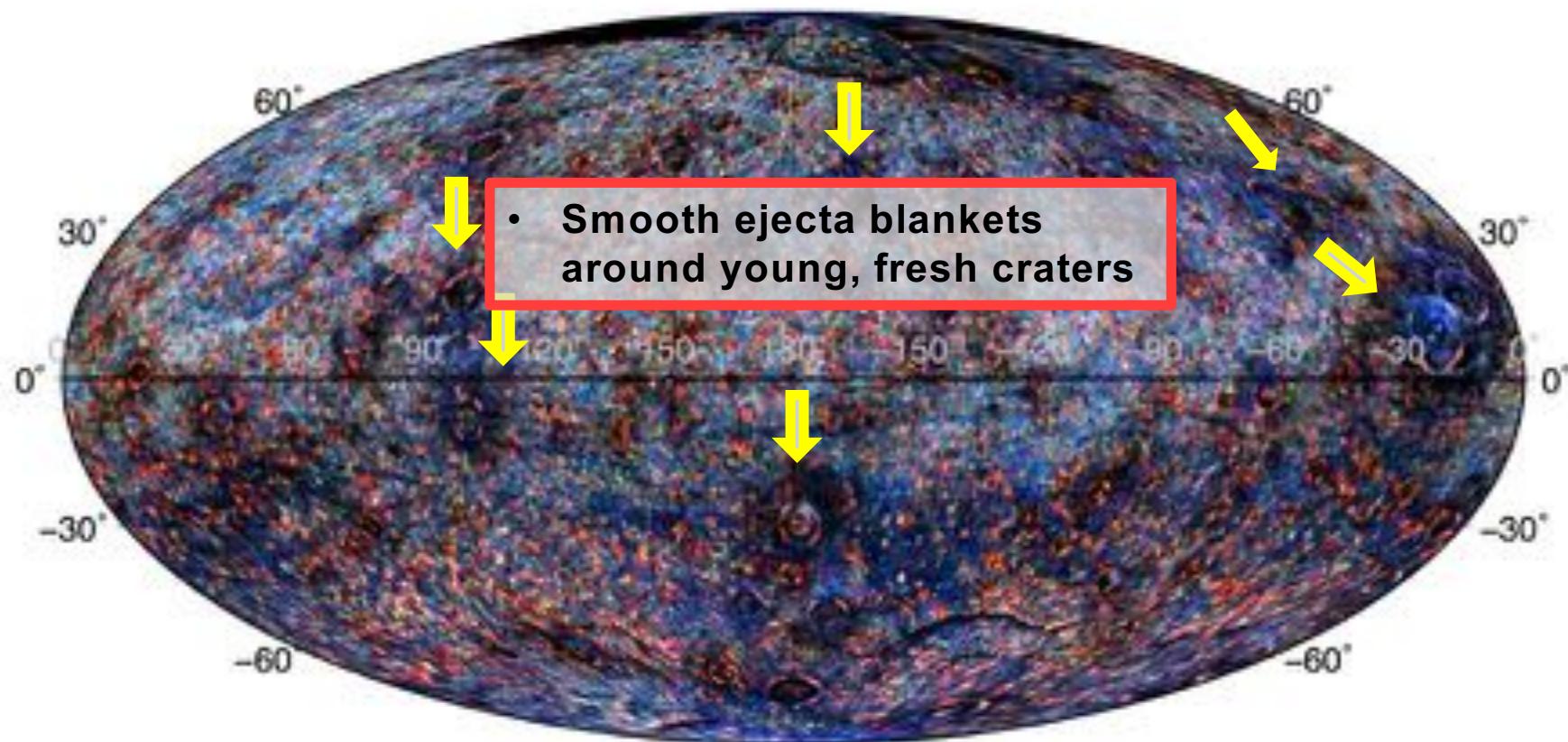
Ermakov et al., in prep

Smooth ejecta blankets

B=1065m/497m

G=2769m/1349m

R=7313/3621 m



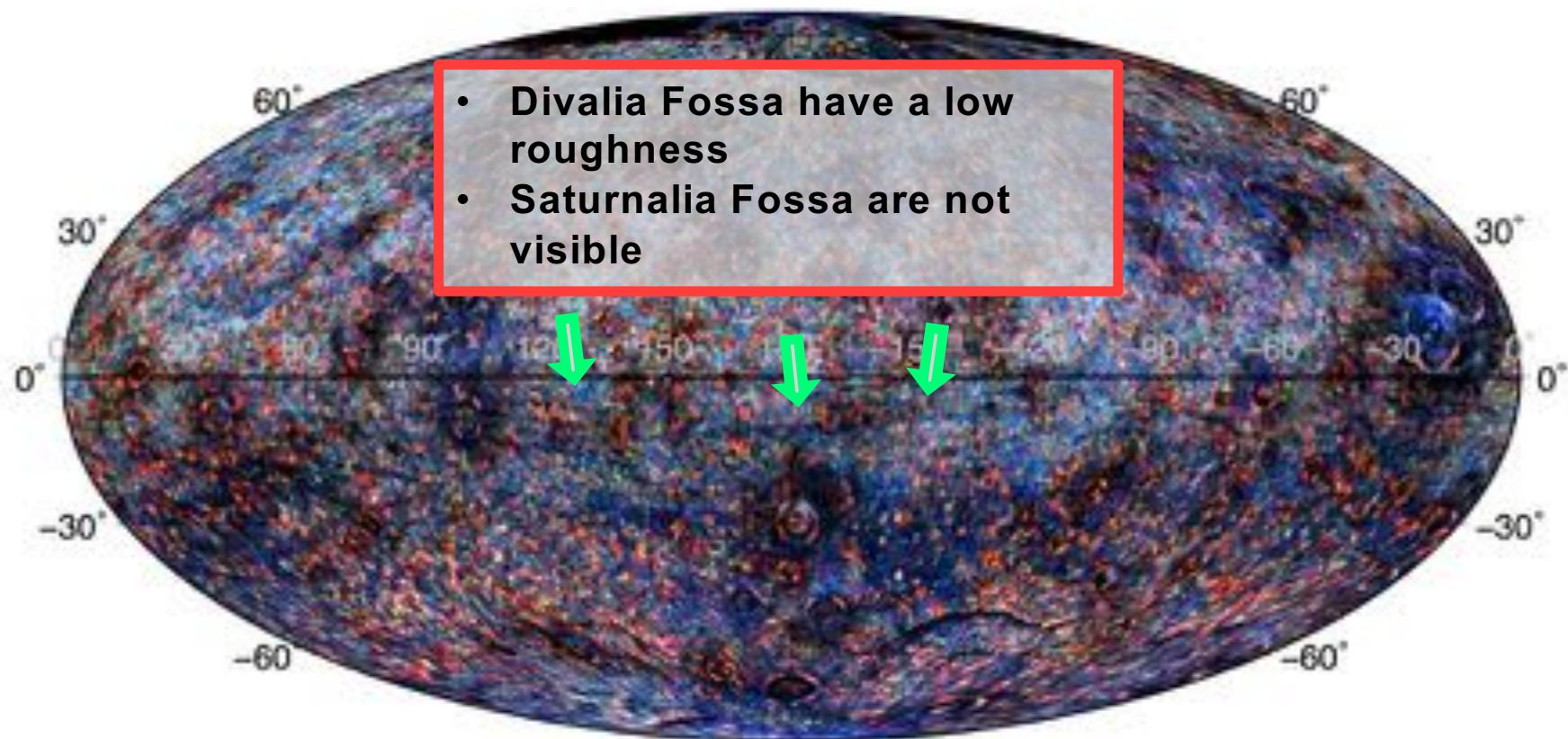
Ermakov et al., in prep

Divalia Fossa

B=1065m/497m

G=2769m/1349m

R=7313/3621 m



Ermakov et al., in prep

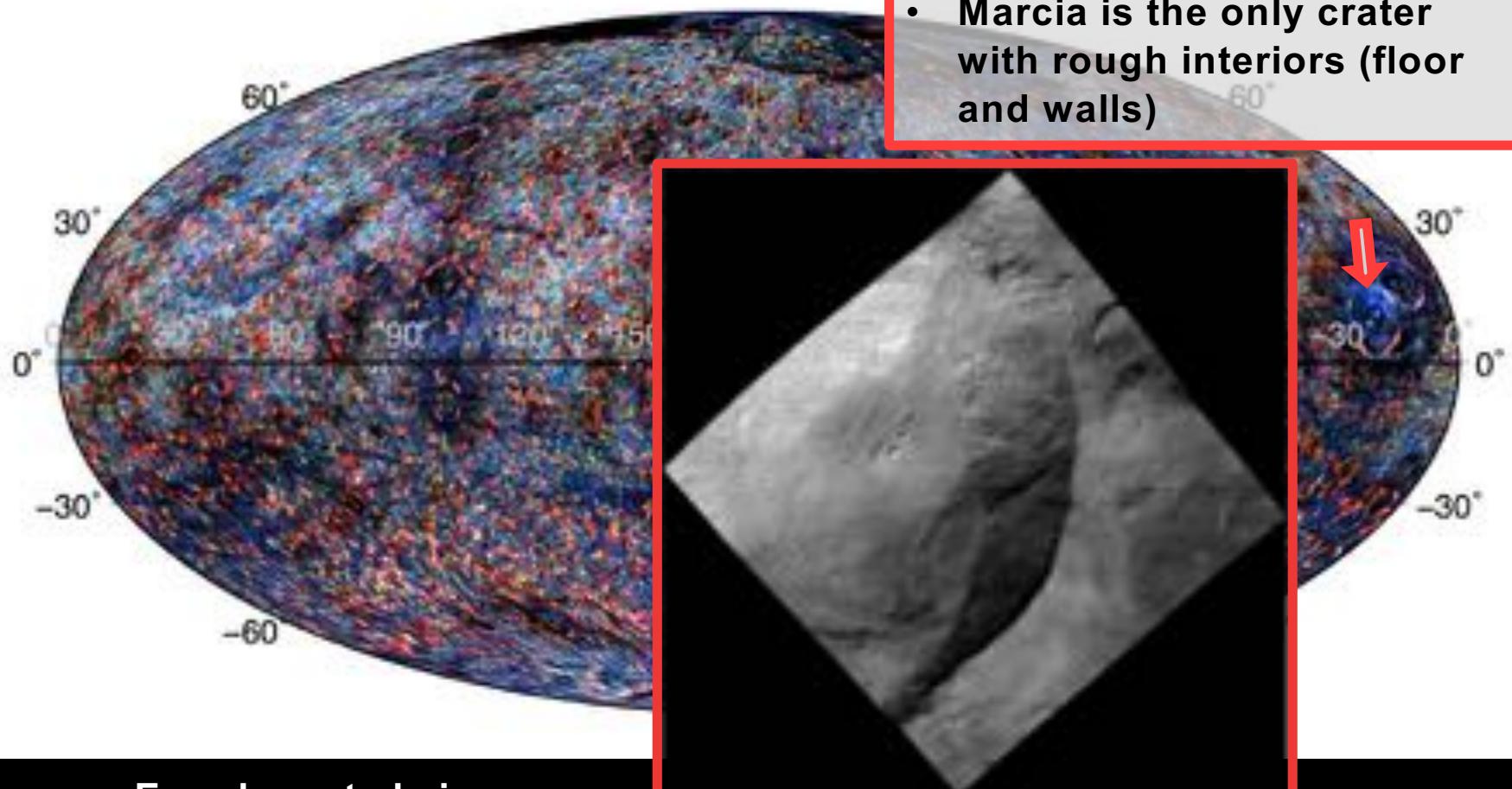
Marcia

B=1065m/497m

G=2769m/1349m

R=7313/3621 m

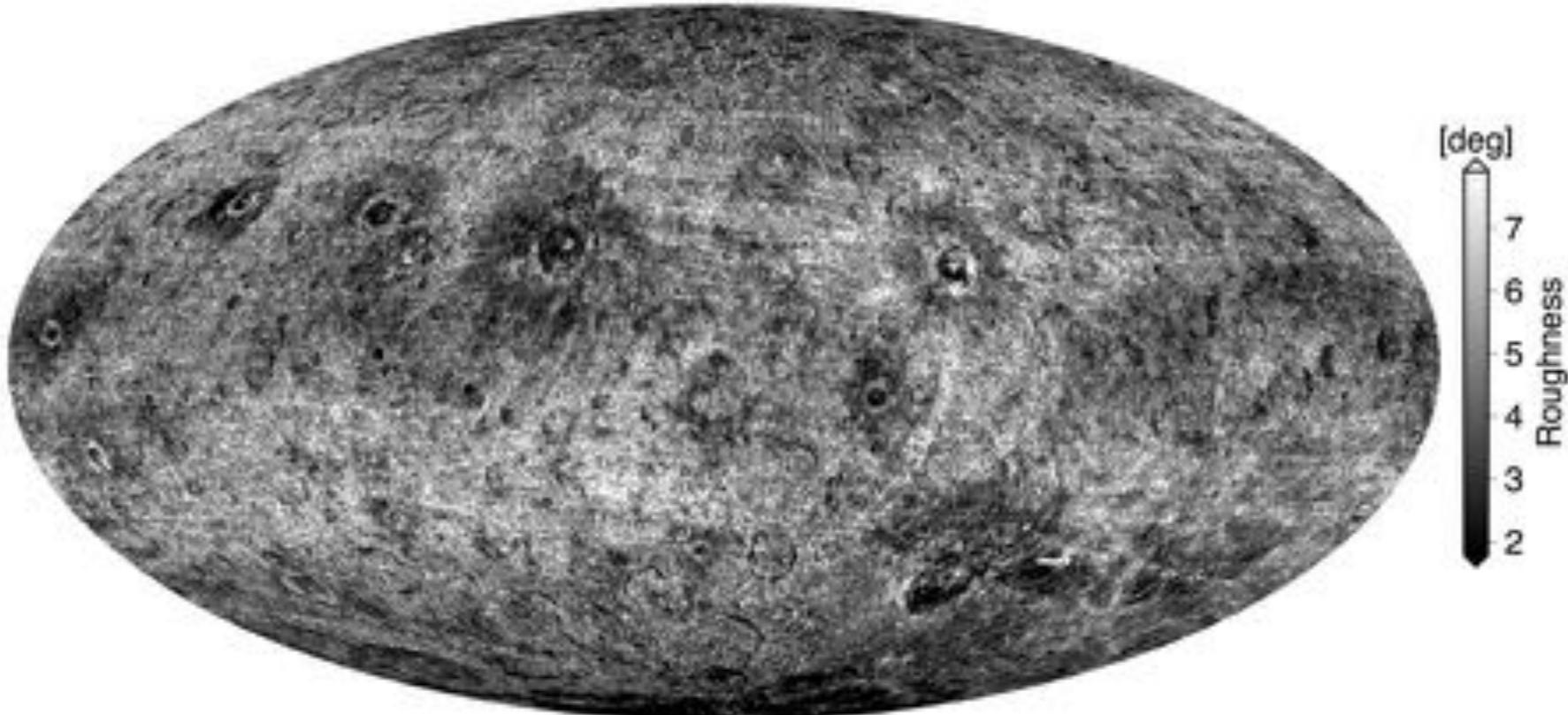
- Marcia is the only crater with rough interiors (floor and walls)



Ermakov et al., in prep

Ceres SPC roughness composite

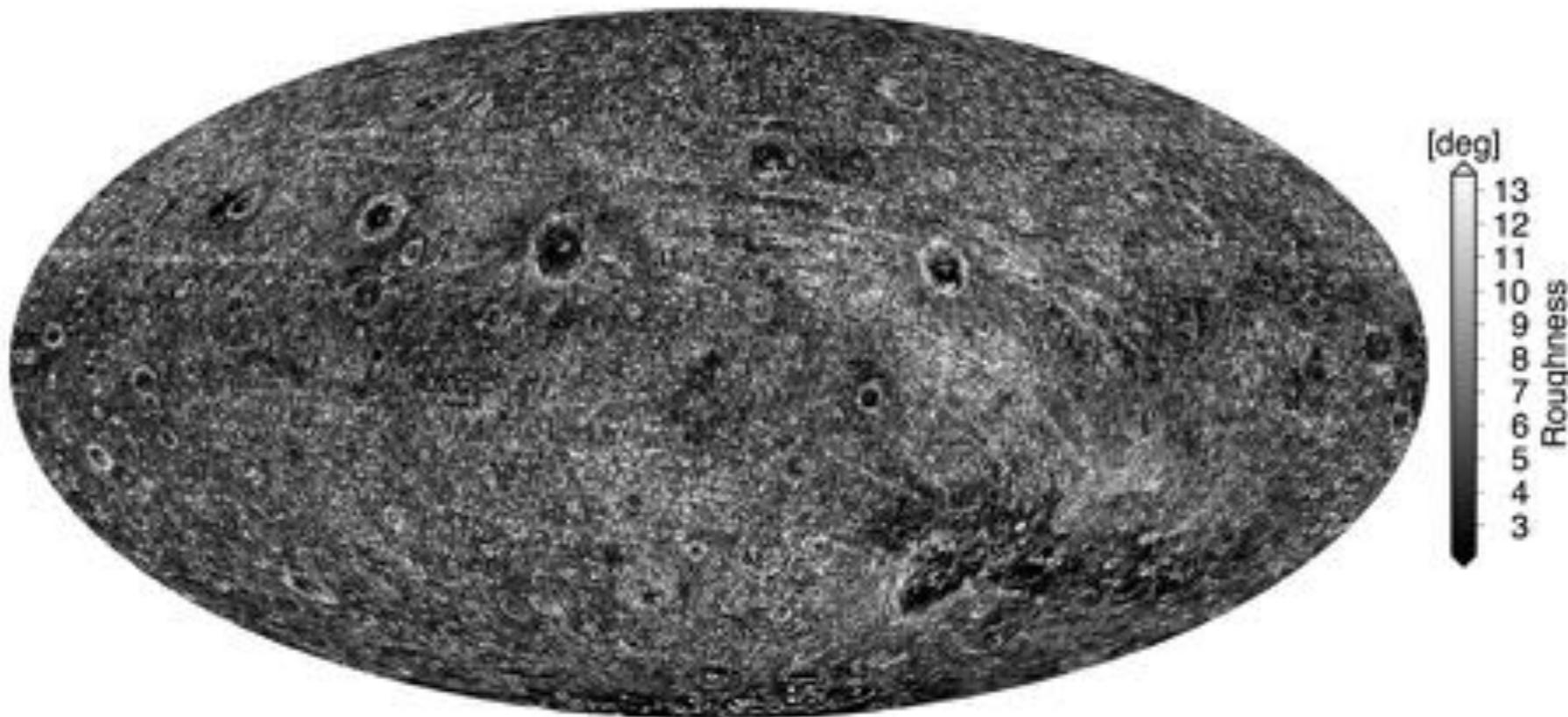
B=1230/574 m



Ermakov et al., in prep

Ceres SPC roughness composite

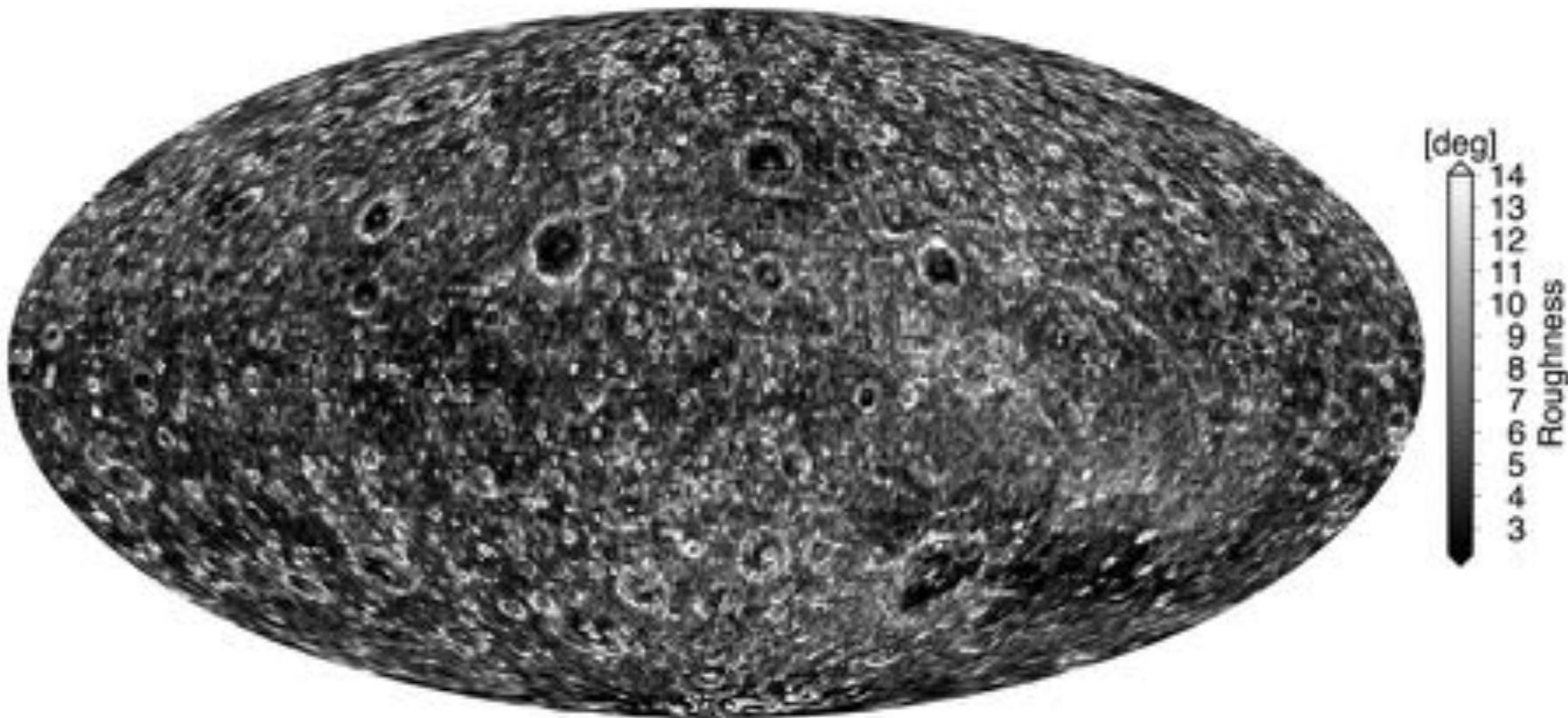
G=3198/1558 m



Ermakov et al., in prep

Ceres SPC roughness composite

R=7134/3526 m



Ermakov et al., in prep

Ceres SPC roughness composite

B=1230/574 m

G=3198/1558 m

R=7134/3526 m



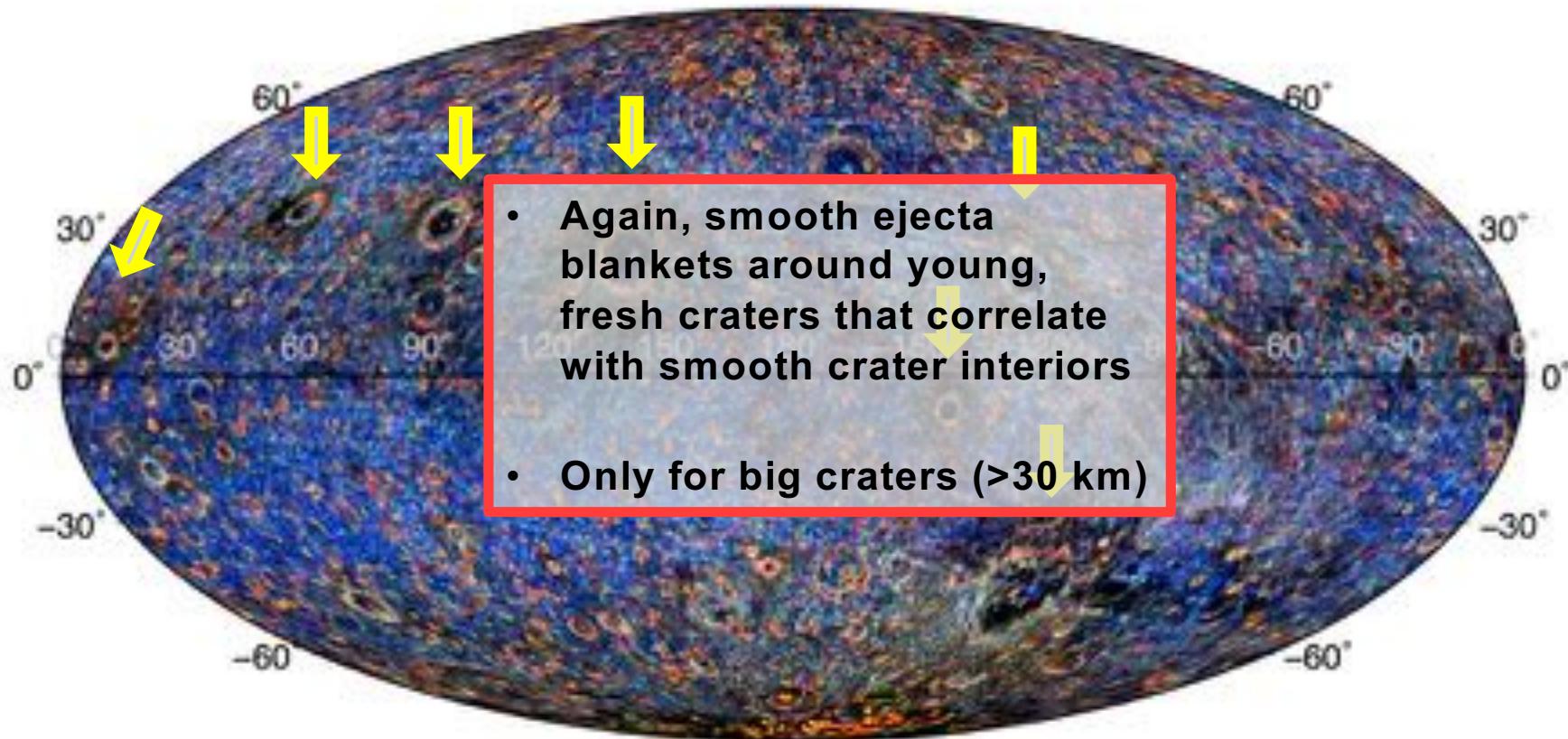
Ermakov et al., in prep

Smooth ejecta blankets

B=1230/574 m

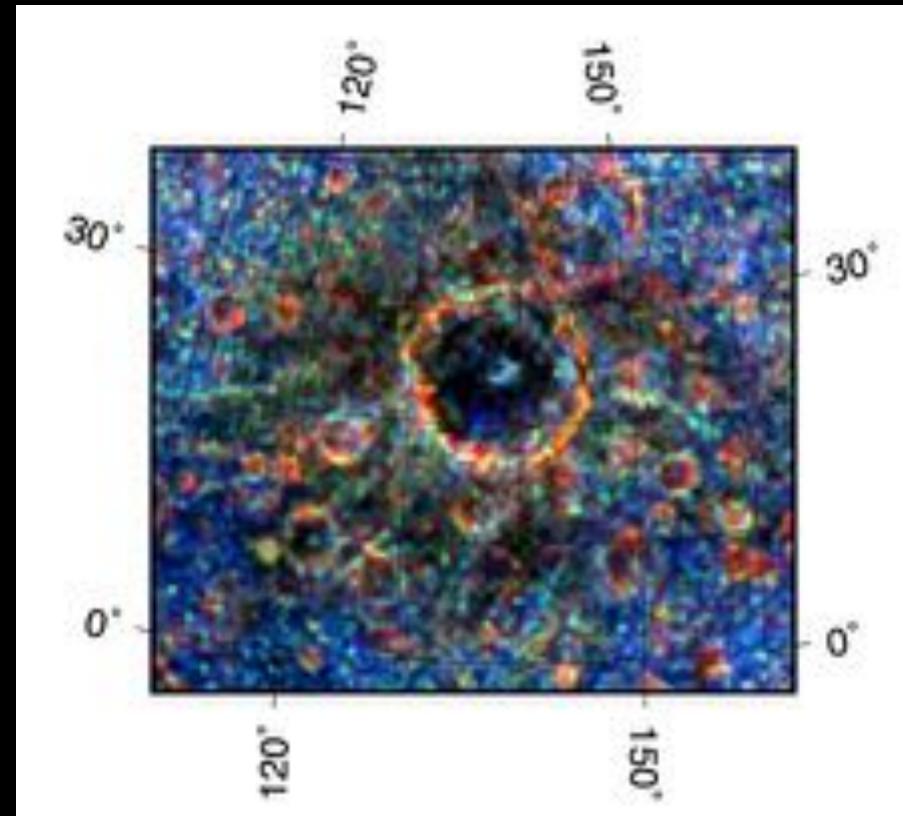
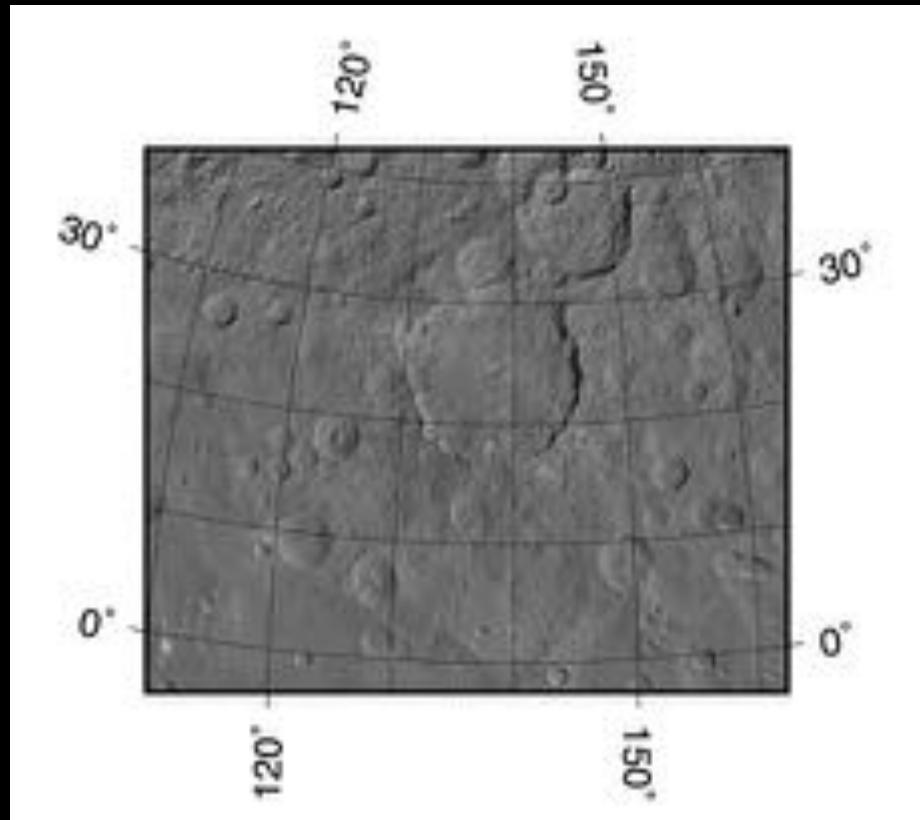
G=3198/1558 m

R=7134/3526 m



Ermakov et al., in prep

Smooth ejecta blankets (Dantu)



Lunar roughness



Kreslavsky et al., 2013

Mercury roughness

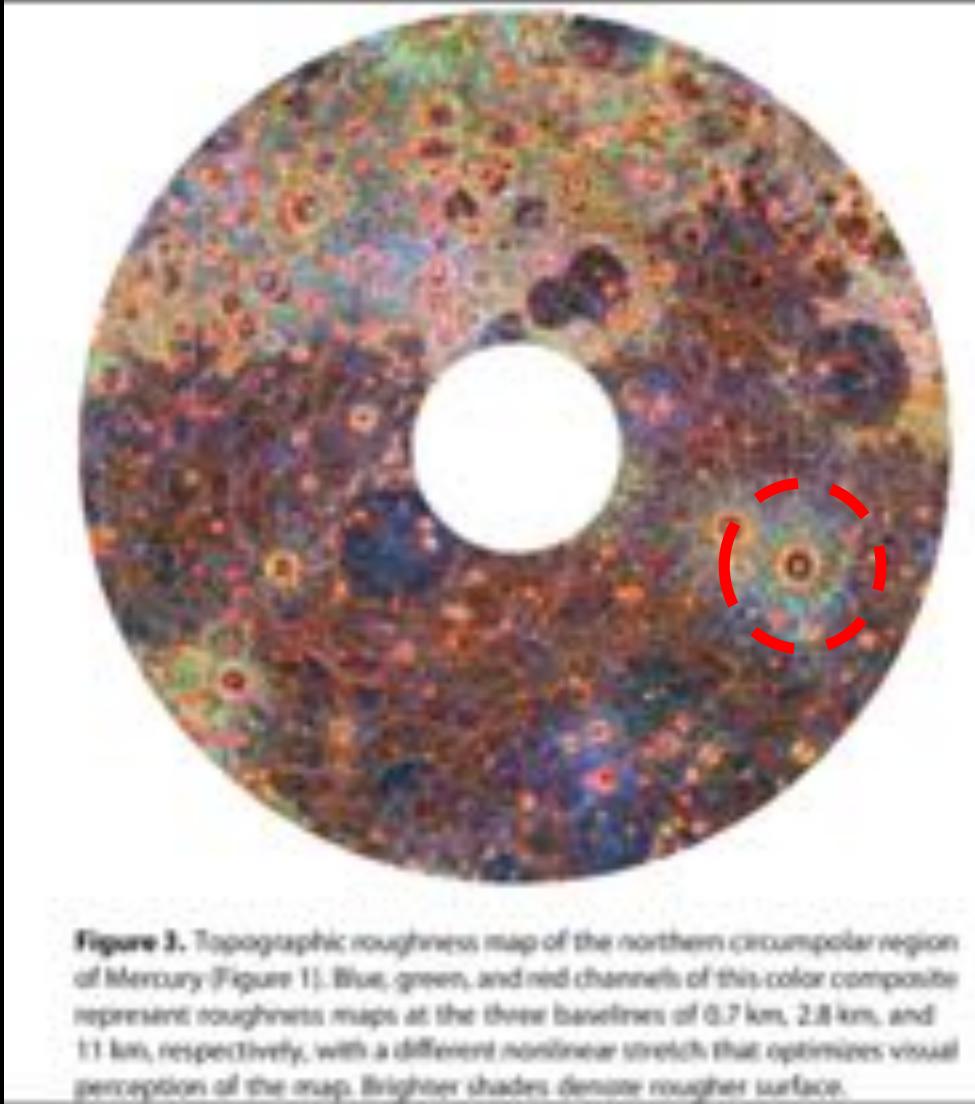


Figure 3. Topographic roughness map of the northern circumpolar region of Mercury (Figure 1). Blue, green, and red channels of this color composite represent roughness maps at the three baselines of 0.7 km, 2.8 km, and 11 km, respectively, with a different nonlinear stretch that optimizes visual perception of the map. Brighter shades denote rougher surface.

Kreslavsky et al., 2014

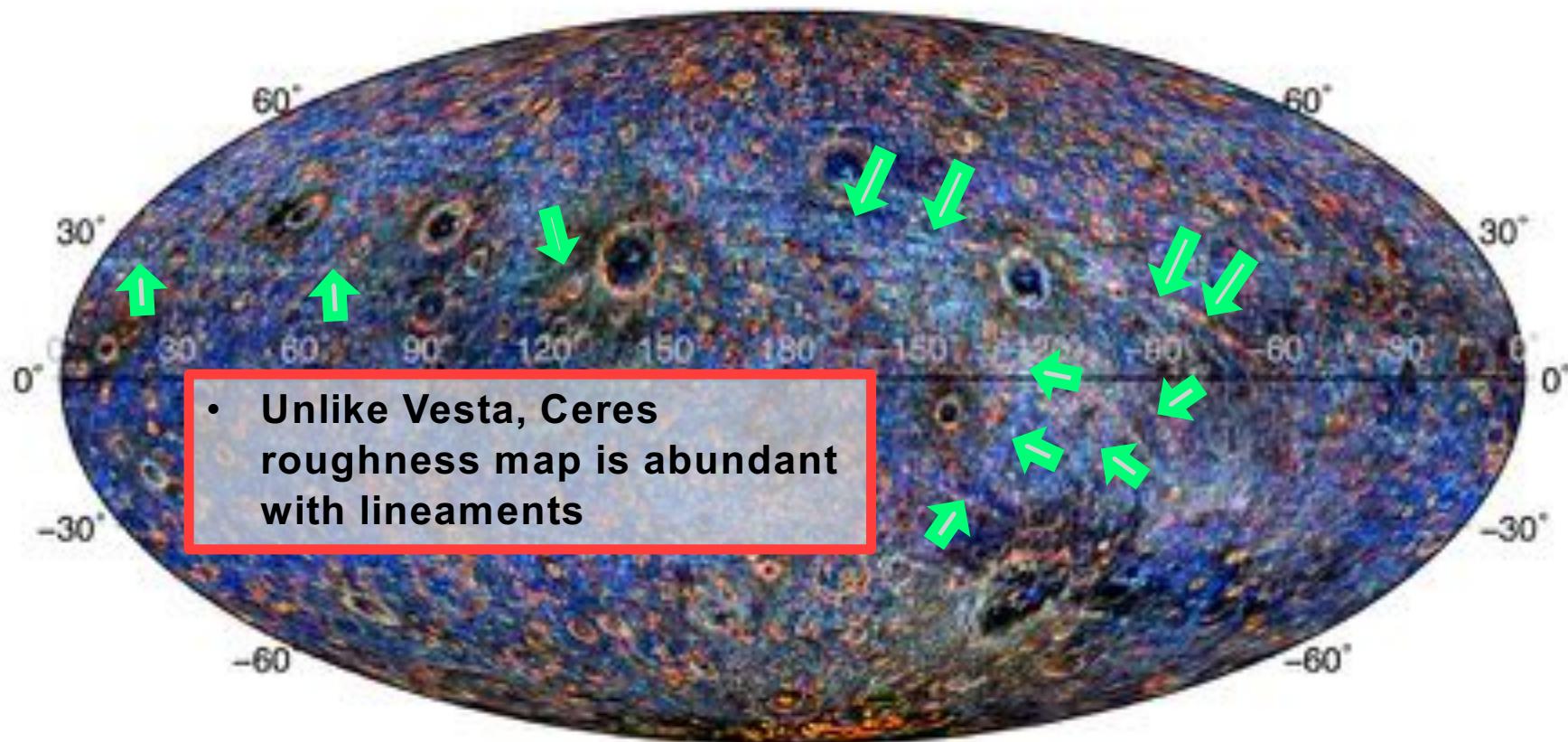
COSPAR, 14-22 July, 2018, Pasadena, CA, USA.

Lineaments

B=1230/574 m

G=3198/1558 m

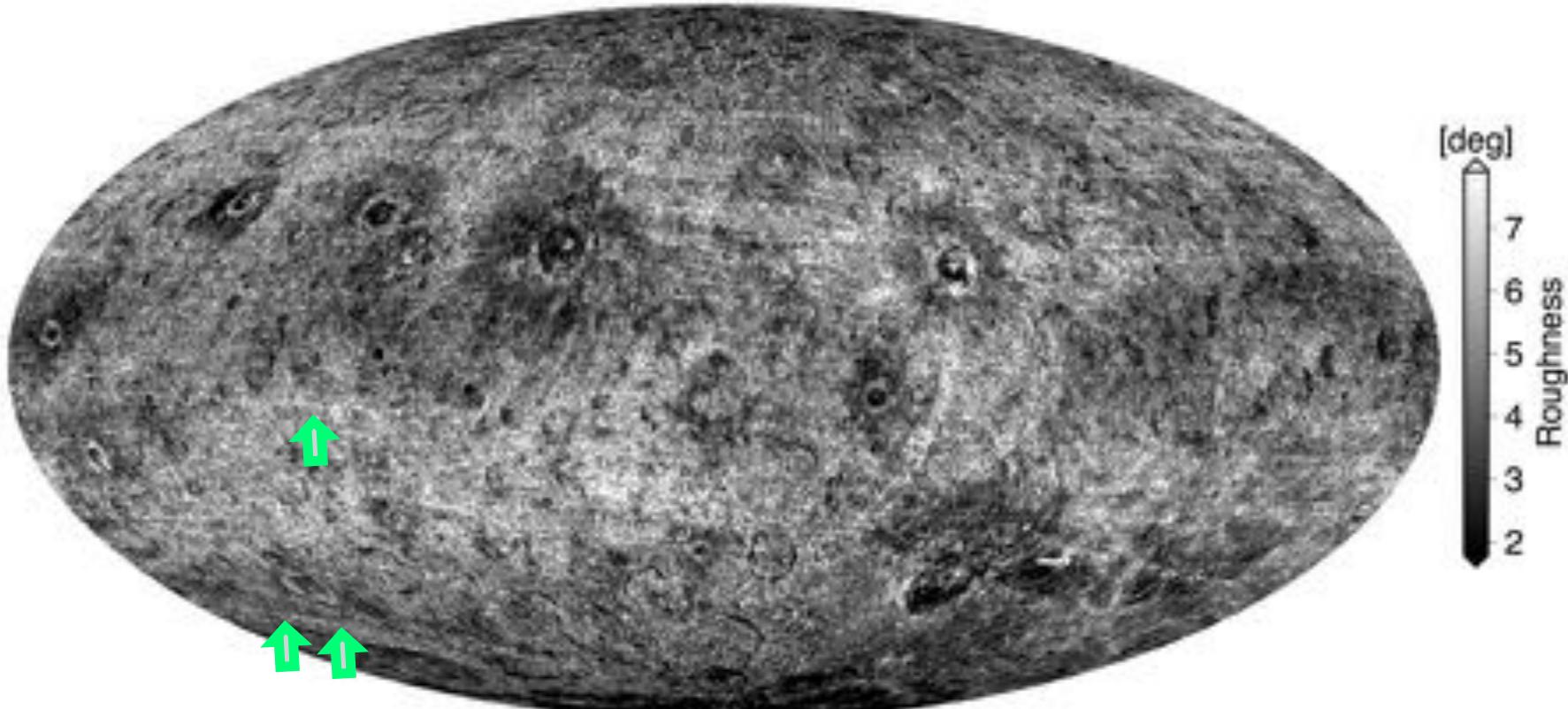
R=7134/3526 m



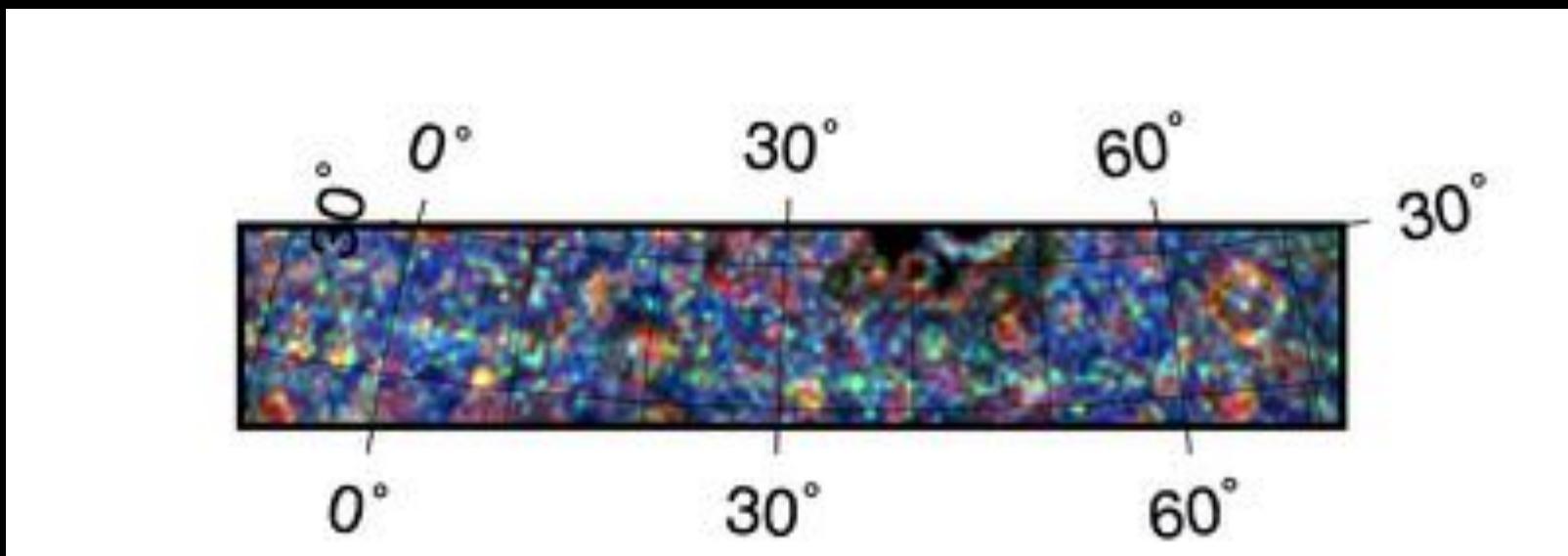
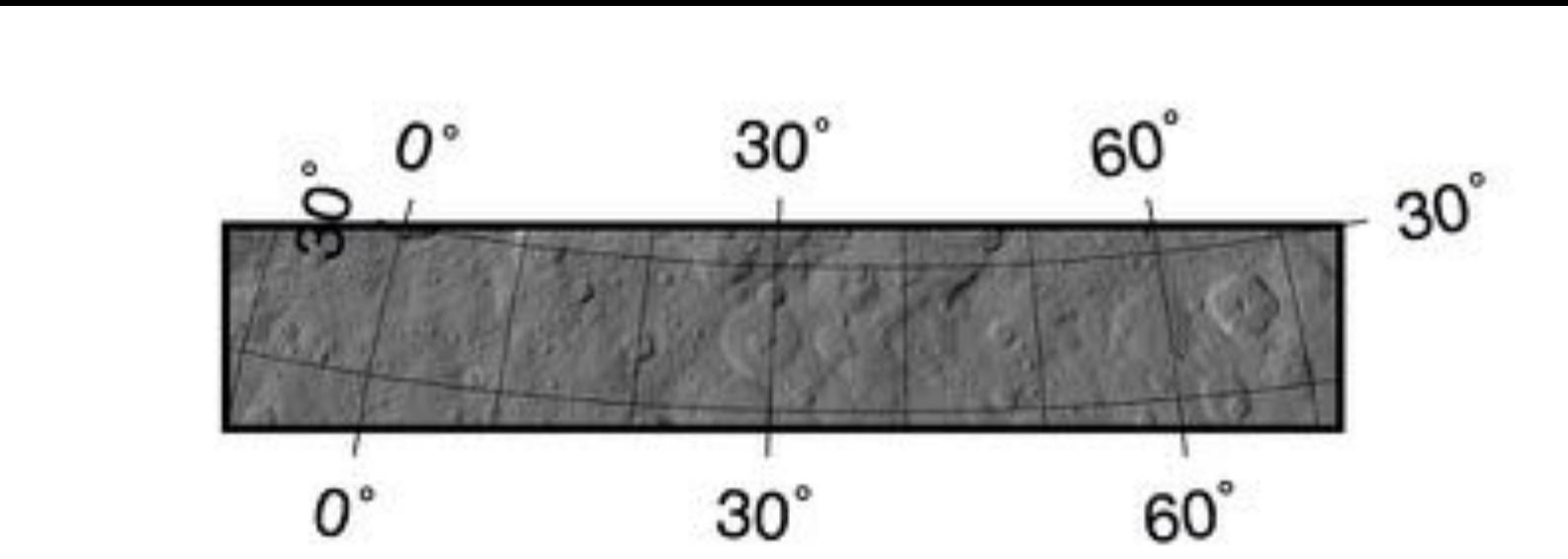
Ermakov et al., in prep

Lineaments

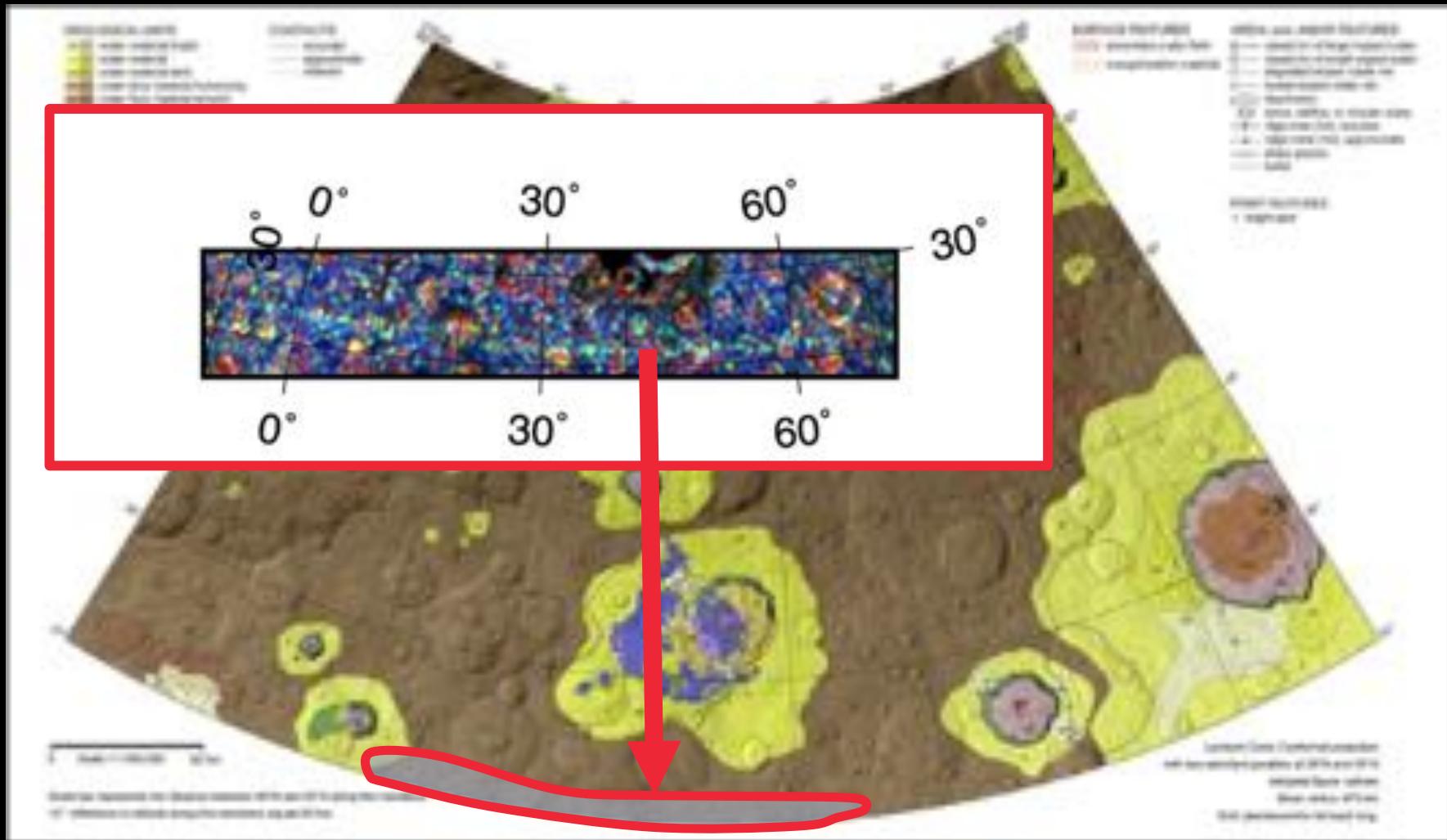
B=1230/574 m



Example of a roughness lineament on Ceres



Example of a roughness lineament on Ceres



Pasckert et al., 2017

Large basins

B=1230/574 m

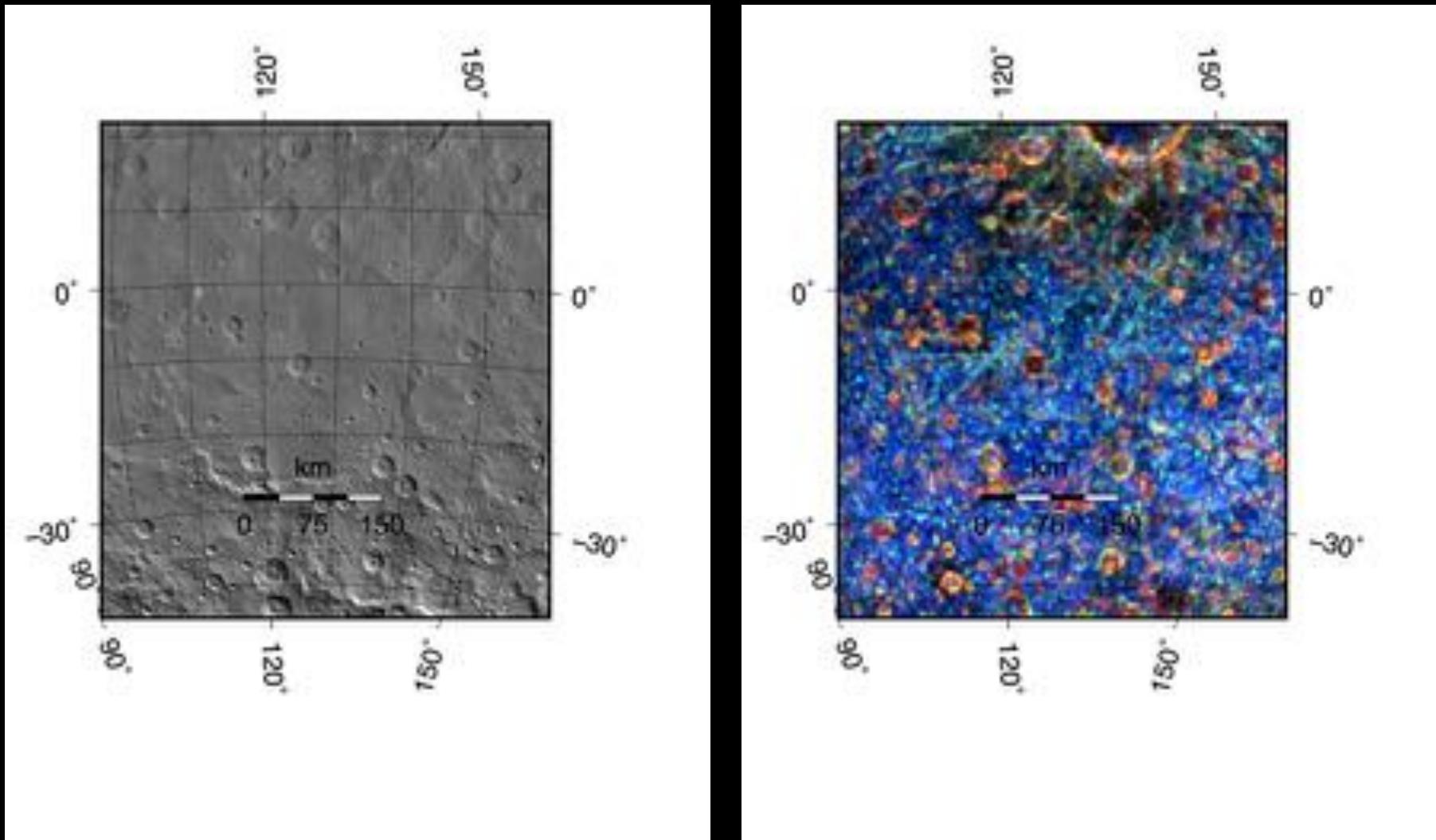
G=3198/1558 m

R=7134/3526 m

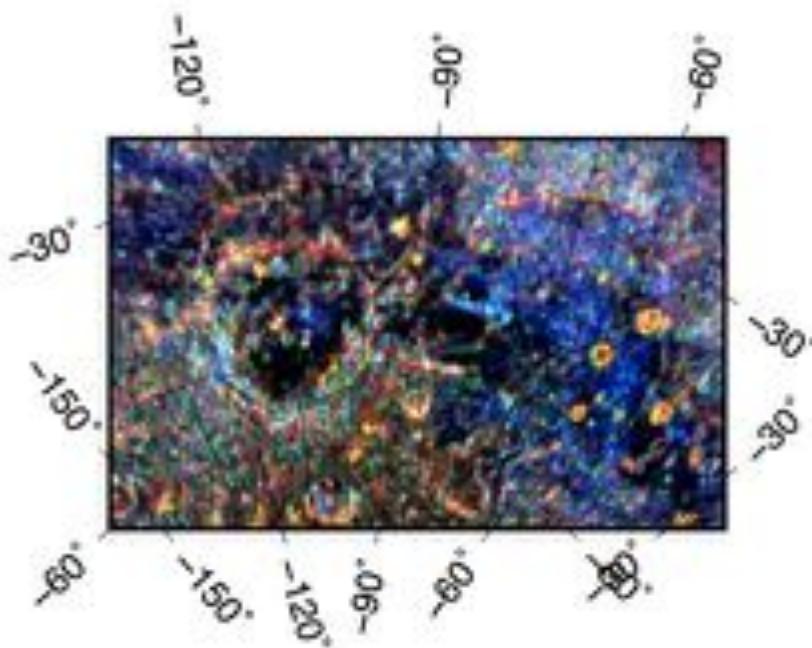
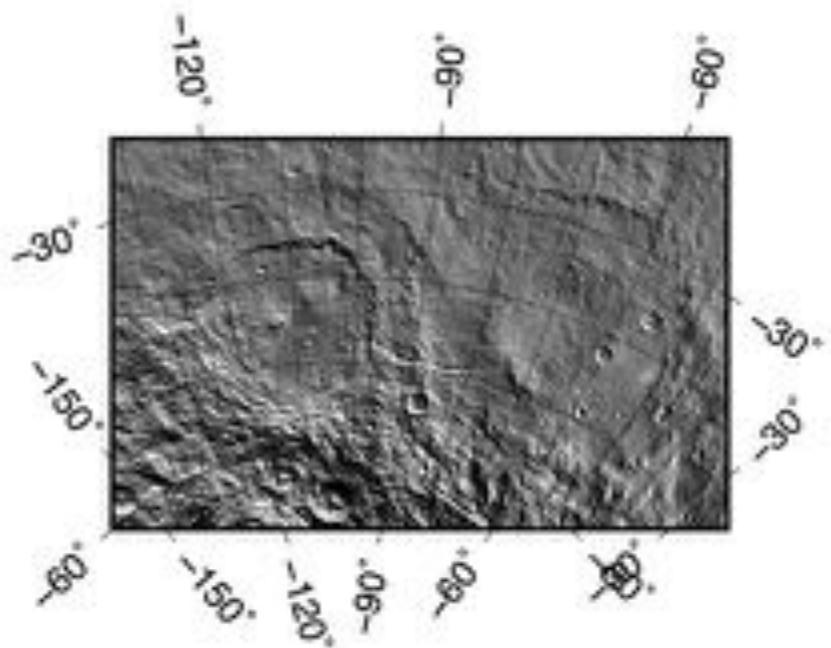


Ermakov et al., in prep

Kerwan



Urvara and Yalode



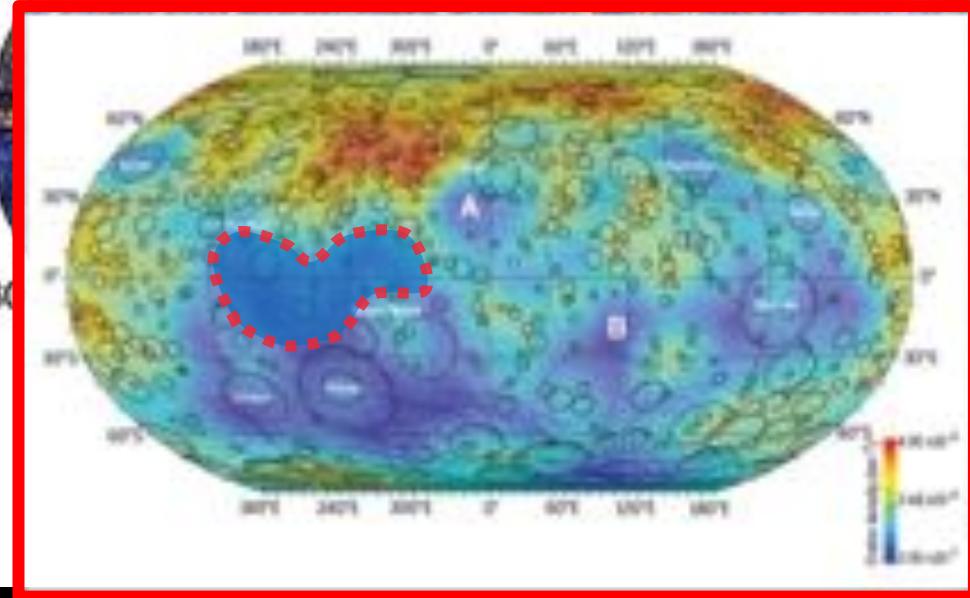
Diffuse low roughness region

B=1230/574 m

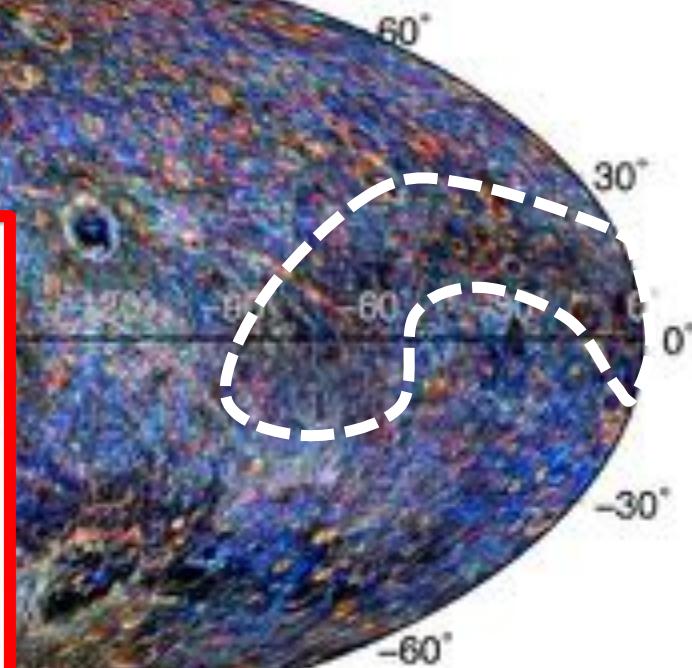
G=3198/1558 m

R=7134/3526 m

- Diffuse low roughness region broadly correlates with low crater density area



Ermakov et al., in prep



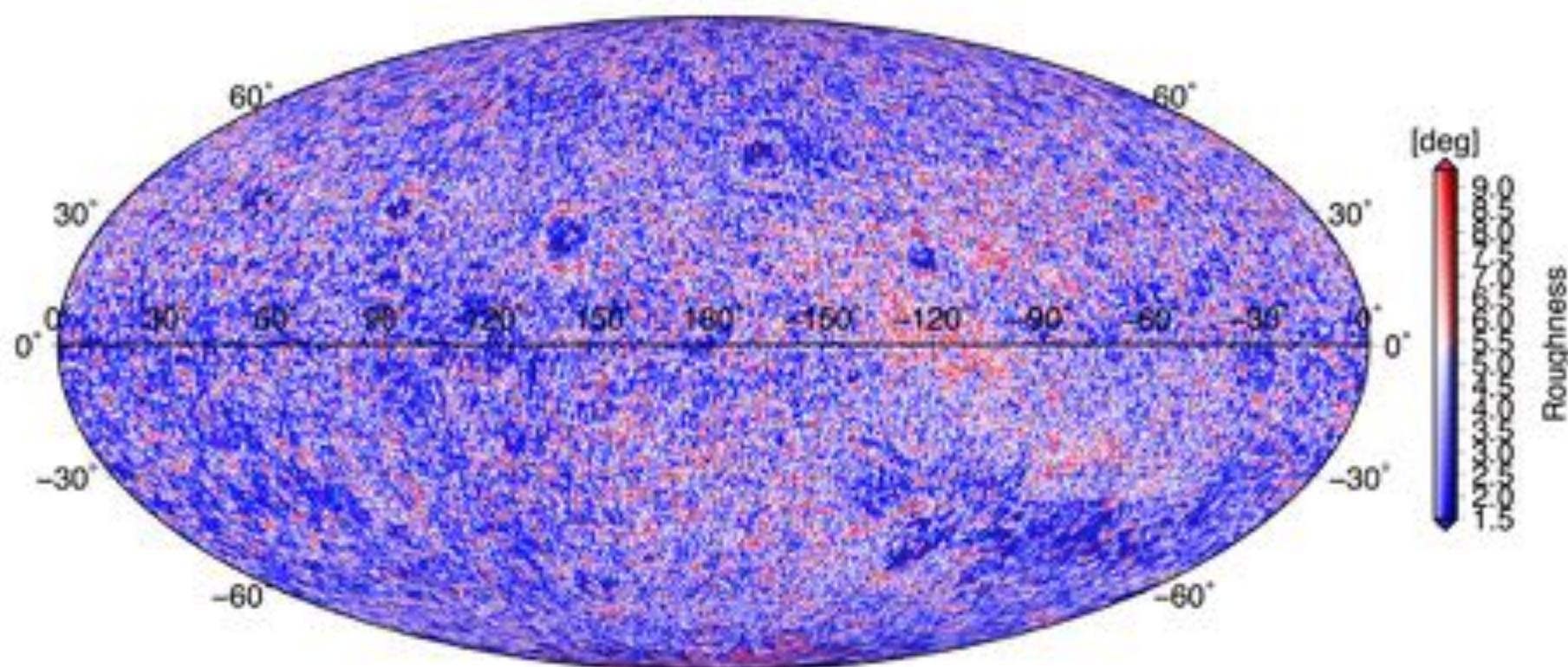
Conclusions

- Vesta and Ceres may have a higher angle of repose (ϕ) than Mars and the Moon
 - $\phi_{\text{Vesta}}=35^\circ$; $\phi_{\text{Ceres}}=34^\circ$; $\phi_{\text{Mars}}=31^\circ$; $\phi_{\text{Moon}}=30^\circ$
 - If interpreted as the dynamic angle of repose, contradicts experiments by Kleinhans et al., 2011
 - Surface gravity? Composition? Particle shape?
- Roughness dichotomy on Vesta and only regional scale variations on Ceres
- Smooth ejecta blankets on Vesta and Ceres as opposed to rough ejecta blankets on Moon and Mercury
- Abundant ejecta rays on Ceres and absence thereof on Vesta
 - Easier to produce topographically-expressed secondaries on Ceres?
 - Could be caused by different surface composition and/or different impact velocity of the secondaries ($v_{\text{esc,vesta}}=0.36 \text{ km/s}$, $v_{\text{esc,ceres}}=0.51 \text{ km/s}$)
 - Curving ejecta rays due to rotation on Ceres
- Produced roughness maps could aid geologic mapping of Vesta and Ceres

Back-up

Ceres roughness at long scales (SPC)

3526/7134 m



Ceres roughness at long scales (SPG)

3526/7134 m

